Bowdens Silver Project

TSF and WRE Closure Cover Design

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Synopsis

This report presents the details for the closure cover design for the tailings storage facility (TSF) and waste rock emplacement (WRE) for the Bowdens Silver Project located near Lue, New South Wales.

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201012-00683-SS-REP-0001 – Bowdens Silver Project - TSF and WRE Closure Cover Design

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Acronyms and Abbreviations	
AE	Actual evaporation
ARD	Acid rock drainage
BOM	Bureau of Meteorology
CPE	Chlorinated polyethylene
GARD	Global Acid Rock Drainage Guide
GCL	Geosynthetic clay liner
HDPE	High density polyethylene
K_{SAT}	Saturated hydraulic conductivity
LGO	Low grade ore
LAI	Leaf area index
LLDPE	Linear low density polyethylene
m/s	Metres per second
MEND	Mine Environment Neutral Drainage Program
NAF	Non-acid forming
PAF	Potential acid forming
PE	Potential evaporation
PEA	Preliminary environmental assessment
PSD	Particle size distribution
PVC	Polyvinyl chloride
RWC	R.W. Corkery & Co Pty Limited
TSF	Tailings storage facility
WRE	Waste rock emplacement

1 Introduction

Bowdens Silver Pty Limited (Bowdens Silver), a wholly owned subsidiary of Silver Mines Limited, is developing the Bowdens Silver Project (the Project) located near Lue, approximately 26 km east of Mudgee in central New South Wales, Australia. The Project is a low-sulphidation, epithermal silver deposit principally hosted in siliceous volcanic rocks with silver mineralisation associated with zinc and lead sulphides.

The Project comprises a main open cut pit and two satellite open cut pits, a processing plant, Tailings Storage Facility (TSF), temporary and permanent waste rock landforms, accesses and haul roads, acoustic barriers and associated infrastructure. **Figure 1** presents the general site layout of the Mine Site.

The TSF design, presented in the ATC Williams TSF Preliminary Design Report (dated May 2020), comprises a single cell valley-type TSF, with three sub-ordinate valleys connecting to the main valley where the embankment is located (refer **Figure 1**). The TSF is to be constructed as a three-stage facility using the downstream raising method with a final tailings beach surface area of approximately 114ha.

The preliminary waste rock emplacement (WRE) design was developed to incorporate a haul road, flood protection bund/roadside acoustic barrier, leachate management dam and a low grade ore (LGO) stockpile.

In 2018, Advisian was requested to re-evaluate and update a closure cover system design that had been developed by WorleyParsons (now Advisian) in 2014 for the former Project Owners, Kingsgate Bowdens Pty Ltd. The updated closure cover system was to be based on the revised TSF and WRE designs in order to meet mine closure requirements. This report presents the results of Advisian's re-evaluation and update.

1.1 Objectives

The main objective of the closure cover design is to develop an acceptable cover for the final TSF and WRE surfaces in order to:

- contain all potentially acid forming (PAF) materials by full encapsulation so as to limit sulphide oxidation and control the release of acidic seepage from both facilities;
- protect the final landform surfaces from erosion;
- minimize ingress and percolation of rainfall into the encapsulated tailings and waste rock material thus reducing the potential for seepage from both facilities; and
- meet the Project's long-term closure objectives and regulatory requirements.

It is understood the Project's long-term objectives for rehabilitation of the areas disturbed throughout the Project life focus upon the creation of landforms beyond the open cut pit void that are geotechnically stable, blend as far as practicable, with the surrounding landform, and do not contribute to off-site contamination of air quality and water quality, particularly with respect to acid rock drainage.

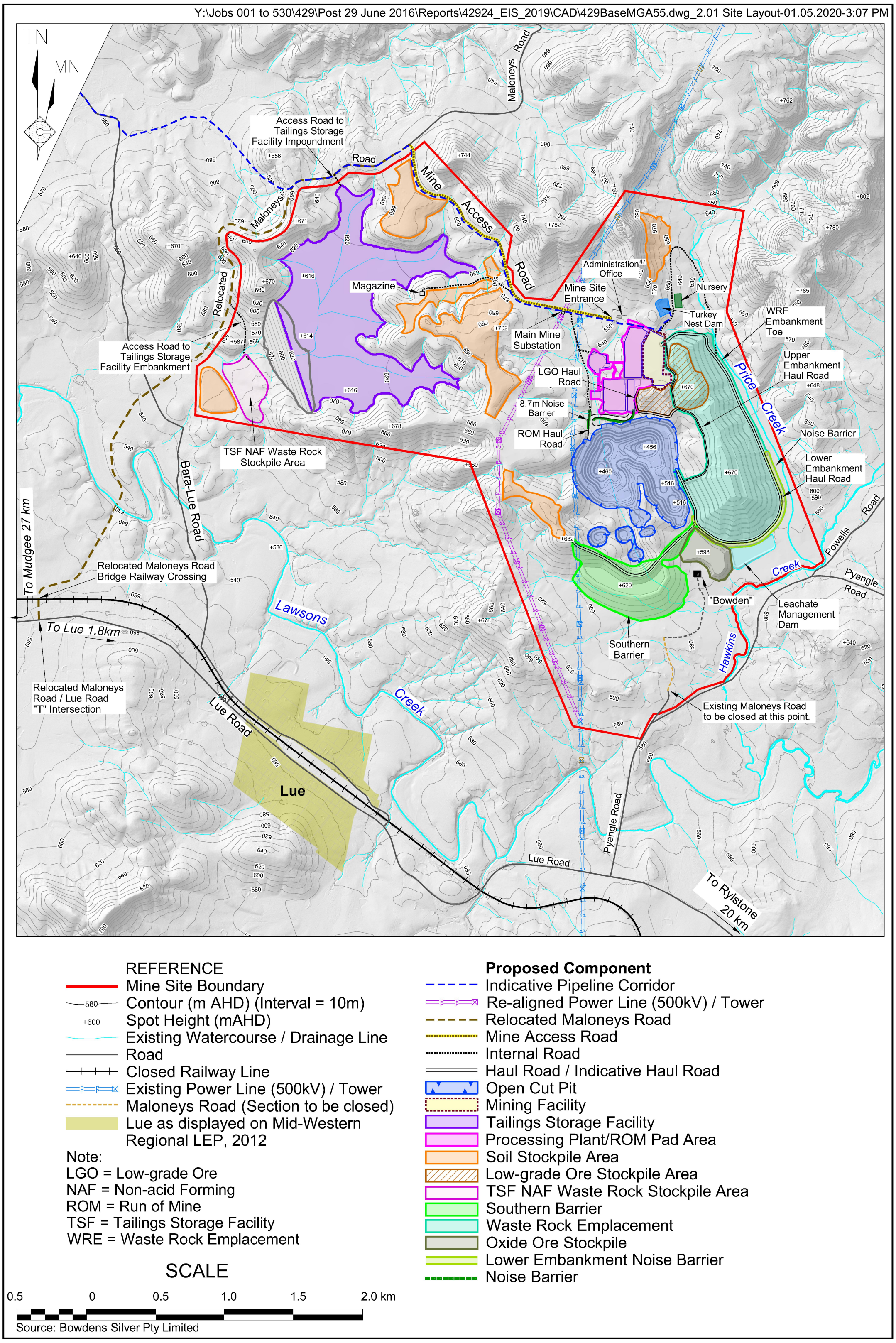


Figure 1 - Mine Site layout (source: R.W. Corkery & Co. Pty Limited, 2020).

The generic comments made below identify the design concepts required for overall geochemical control in line with mining industry best-practice for the secure containment of reactive varieties of mine waste rock:

- The upper-surface of the final landform would have a surface hydrology which allows for the controlled shedding of runoff generated by intense storm events.
- The cover design allows for moisture infiltration into the cover materials and storage for uptake by the vegetative cover, thereby sustaining the vegetation and preventing further ingress of moisture and the subsequent interaction with the reactive materials stored in the TSF and WRE thus preventing contaminants being transmitted into the groundwater system via seepage.

2 Scope of Work

Based on the objectives outlined in Section 1.1, the following scope of work has been carried out by Advisian:

- Review of the available Project-related documents and site specific climate data, which remains the same as used in 2014. The 2014 dataset is considered to still be relevant at this stage of the Project due to the long-term nature (125 years) of the dataset.
- Preliminary modelling, using simplified site specific climatic conditions, of the soil cover configuration recommended by the Project specialist soils consultant.
- Discussion with the Project stakeholders regarding feasibility of the conceptual design and availability of materials for use in construction of the cover.

2.1 Available Information

The following project publicly available information and project documentation was used in the preparation of this report:

- Climate data from Bureau of Meteorology website (http://www.bom.gov.au)
- Preliminary Environmental Assessment (PEA) for Bowdens Silver Project, prepared in conjunction with R.W. Corkery & Co. Pty. Limited, November 2016
- Tailings Storage Facility for Bowdens Silver Project – TSF Preliminary Design Report, prepared by ATC Williams, 2020
- Bowdens Silver Project – Materials Characterisation – Part 3 of Specialist Consultant Studies Compendium; prepared by Graeme Campbell and Associates Pty Ltd, 2020
- Preliminary Design of PAF Waste Rock Emplacement, Low Grade Ore and Oxide Ore Stockpiles and the Southern Barrier (document number 201010-00790-201010-00790-REP-002) prepared by Advisian, 2020
- Previous documentation and internal reports prepared during the development of historic and current projects related to the Mine Site

3 Background Information

3.1 Purpose of Cover Design

Mine waste materials containing certain sulphide minerals can generate acid rock drainage (ARD). The rate at which acid generation occurs depends on several factors including mineralogy, temperature, pH, specific surface area of the mineral grains, geometry of the storage facility, and availability of oxygen and water. Current best practice requires the placement of a cover onto most types of mine waste materials, including tailings and waste rock, at the time of mine closure (MEND 2004).

One of the main objectives of placing a cover system over reactive waste material is to protect the downstream receiving environment following closure of the mine. This is achieved by reducing the net percolation of water into the reactive mine waste materials, thereby reducing effluent seepage volumes (O'Kane and Ayres, 2012). In addition to limiting contaminant release via seepage, the aims of cover systems can include chemical stabilisation of the waste material by limiting the ingress of atmospheric oxygen, limiting the upward movement of process-water into the cover, and provision of a suitable medium for the establishment of sustainable vegetation. An illustrative example of the various types of liquid and vapour flow within a soil cover system is shown in **Figure 2**.

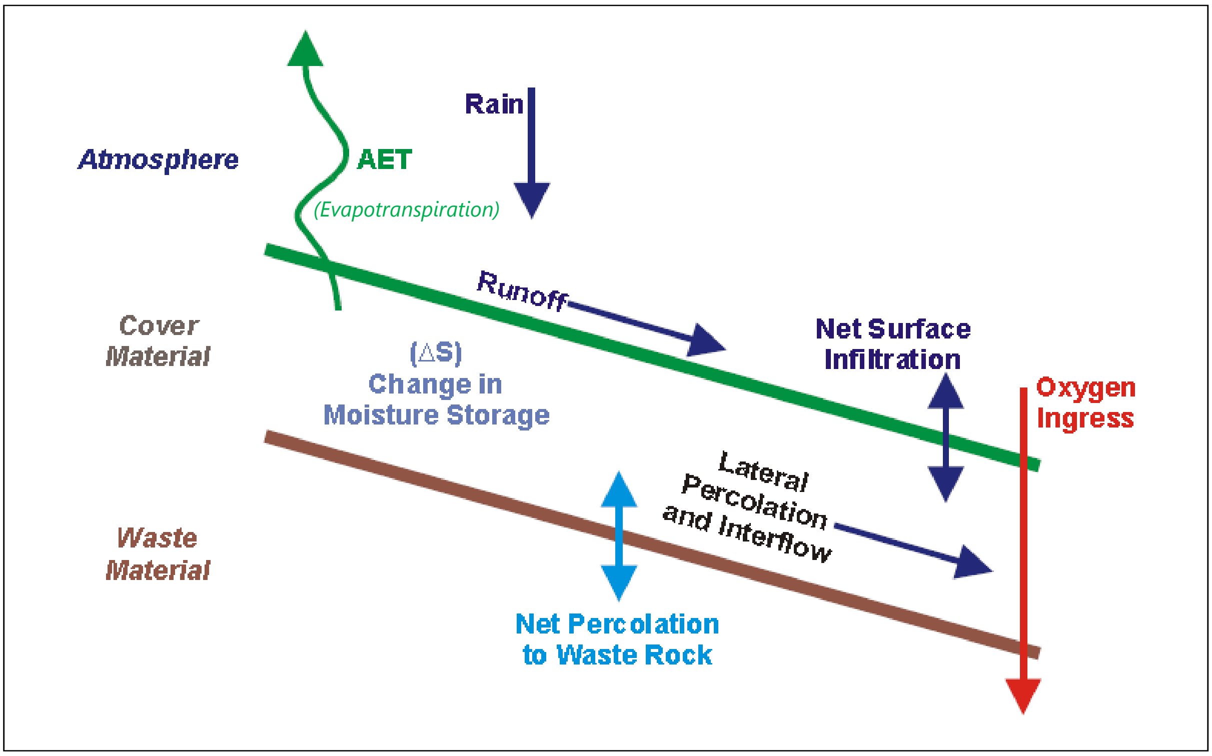


Figure 2 - Conceptual illustration of net percolation (from MEND 2004)

3.2 Types of Covers

The types of covers typically used for tailings and waste rock emplacements are termed soil covers or 'dry' covers (as opposed to water or 'wet' covers). Dry covers are generally made from any combination of earthen, organic, or synthetic materials placed over mine waste.

In the long-term, dry cover systems must interact with climate, hydrology, human activity, vegetation, animals, and settlement of underlying material (GARD, 2012). **Figure 3** shows a tri-linear plot of climate classification, rainfall, and temperature, which provides a useful guide to the different types of covers that may be appropriate for different climates. Based on the long-term, 125 year climate dataset reviewed for the Project (annual rainfall: average ~680mm, standard deviation ~200mm; annual potential evaporation to rainfall ratio: average ~2.7, standard deviation ~1.0) the type of cover required for the Project is one that utilises a combination of the 'store-and-release' and 'water shedding' mechanisms.

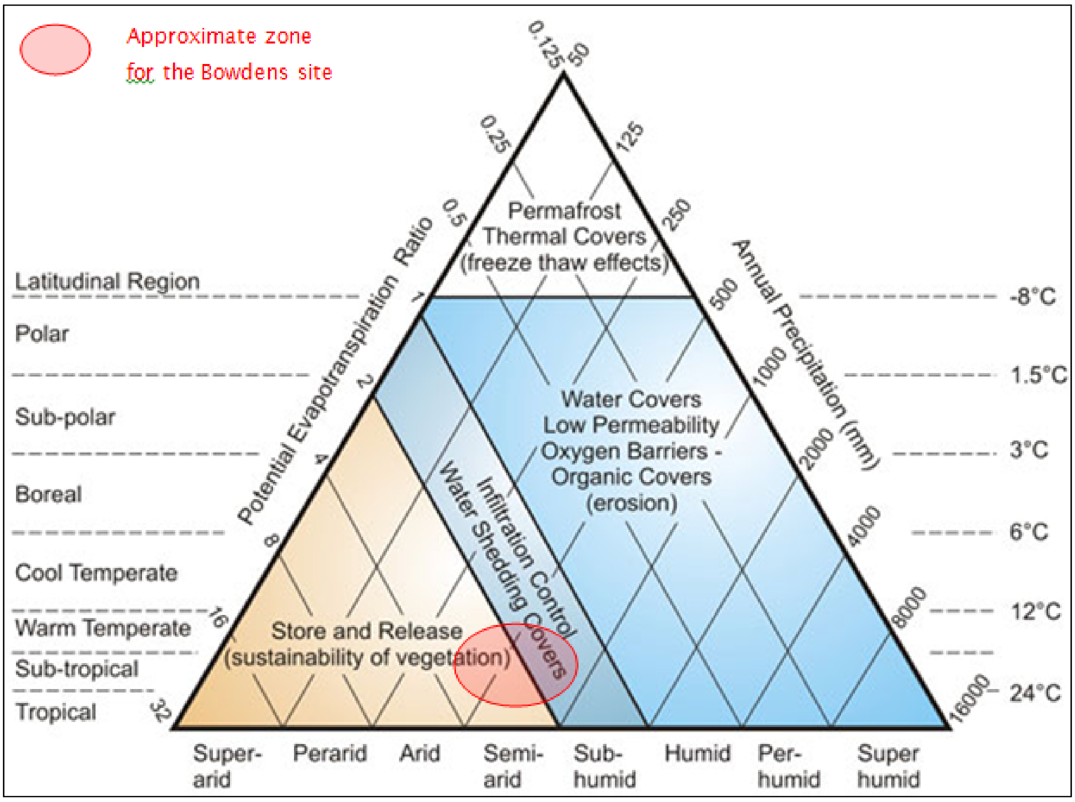


Figure 3 - Covers and climate types (from GARD, 2012)

The 'store-and-release' concept refers to reducing the net percolation of meteoric rainfall into the stored waste material by maximising the storage of moisture in the soil layer of the cover close to the surface, to subsequently be removed from the cover by evapotranspiration. 'Water shedding' refers to covers that minimise net percolation of meteoric rainfall into the stored waste material via the inclusion of a low permeability layer or 'infiltration barrier'.

Although the store-and-release and water shedding mechanisms are often described as separate types of cover systems, this is not necessarily the case. A water shedding cover will typically include a barrier layer (low permeability layer) overlain by a growth medium layer. In reality, the growth medium layer is simply another label for a store-and-release layer as the functionality of the two is the same, i.e. store moisture entering the material via surface infiltration and then release moisture to back to the atmosphere via evapotranspiration. The underlying barrier layer is required to promote water shedding for conditions when the field capacity of the growth medium layer is exceeded, for example during periods of high and/or intense rainfall (O'Kane and Ayres, 2012).

The term 'enhanced store-and-release' is used to describe a cover system that utilises both the store-and-release concept (to meet most of the cover objectives via evapotranspiration) and the water shedding concept (to cope with relatively short-duration seasonal events). The low permeability (water shedding) layer in an enhanced store-and-release cover system could be sourced from locally available silt/clay but must be provided with sufficient soil cover if this material is susceptible to processes such as wet/dry cycling, root penetration, etc. The restricted infiltration layer can lead to increased interflow within the overlying non-compacted layer and increased surface runoff, which increases the risk of surface erosion (O'Kane and Ayres, 2012).

Figure 4 shows three examples of dry covers, including a basic store-and-release system and two enhanced store-and-release systems.

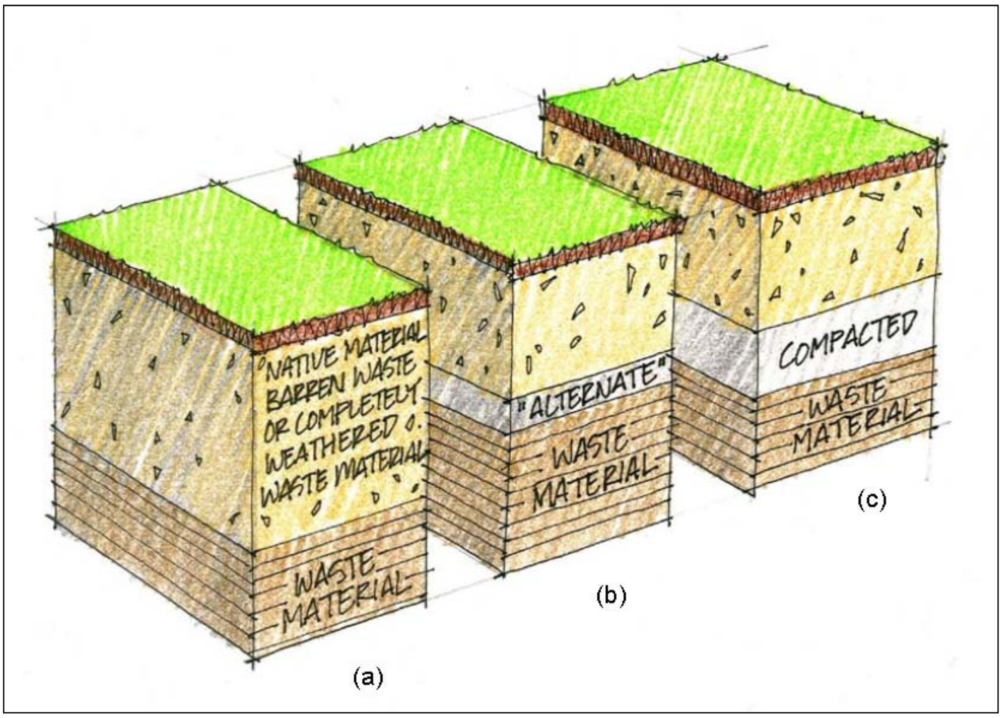


Figure 4 – Schematic of cover systems with store-and-release functionality: (left) basic store-and-release cover system; (middle and right) enhanced store-and-release cover systems showing additional lower hydraulic conductivity layers below the storage layer (from MEND, 2012)

Although it is always preferable to utilise waste materials made available during mining to construct a suitable cover, the inclusion of geosynthetic materials in a cover design can dramatically reduce infiltration and percolation of moisture and oxygen ingress into the stored waste material. The use of a geosynthetic material or geomembrane as part of a cover system is often required if the performance objective of the system is to achieve low net percolation rates (e.g. <5% of precipitation) (MEND, 2012). Geosynthetic materials include polyethylene (PE), high density polyethylene (HDPE), chlorinated polyethylene (CPE), polyvinyl chloride (PVC), linear low-density polyethylene (LLDPE), geosynthetic clay liners (GCLs), and bituminous geomembranes. Synthetics are often subject to degradation by sunlight and must be protected with an earthen cover material.

GCLs are popular geosynthetic barriers in temperate climates and are considered suitable for the Project site. A GCL comprises an approximately 1 cm thick layer of sodium bentonite sandwiched between two geotextiles or glued to a geomembrane. An appropriate thickness of cover material is required above the GCL to prevent dehydration of the bentonite over time; otherwise desiccation cracks that develop in the thin bentonite layer may not swell shut during rewetting (MEND, 2012).

3.3 Unsaturated Flow

The movement of water through unsaturated soil is the principal phenomenon of interest in soil cover design (MEND 2004). The primary issues of concern are the mechanisms responsible for the storage and flow of water in the unsaturated zone. These mechanisms can be defined for each type of soil by the volumetric water content (storage) and the hydraulic conductivity (flow) functions. **Figure 5** and **Figure 6** are presented below to give the reader a better understanding of how these storage and flow characteristics may vary for different soil types.

Figure 5 illustrates the 'capillary rise' effect, showing that pore spaces of different sizes will tend to drain at varying levels of suction (negative pore water pressure). As suction levels increase (i.e. the further one moves above the phreatic surface) coarser grained materials with larger pores have less ability to store moisture in the unsaturated zone than finer grained soils.

Figure 6 illustrates how the hydraulic conductivity of a soil is affected by a change in the moisture content of the soil. When the soil is relatively dry or close to its residual moisture content (left soil mass in **Figure 6**) there is no clear path through which the water can pass, thereby reducing the flow of water through the soil to a minimum. When the soil is fully saturated (right soil mass) the water can flow relatively easily and hydraulic conductivity is at a maximum (k_{sat}). When the soil is partially saturated (middle soil mass) there are limited pathways for the water to flow through and the conductivity will be less than k_{sat}.

It can be seen from these two figures that although a coarser grained soil may have a greater k_{sat} than a finer grained soil due to having a larger number of direct flow paths, once the soil becomes unsaturated the moisture content of the coarser grained material will be significantly reduced thereby lowering the conductivity, whereas the finer grained material may remain closer to saturation thereby retaining a conductivity that may be higher than the coarser grained soil at the same suction level. This concept is important for the store-and-release layers within a soil cover which relies on infiltrated moisture being transported back towards the surface for evapotranspiration.

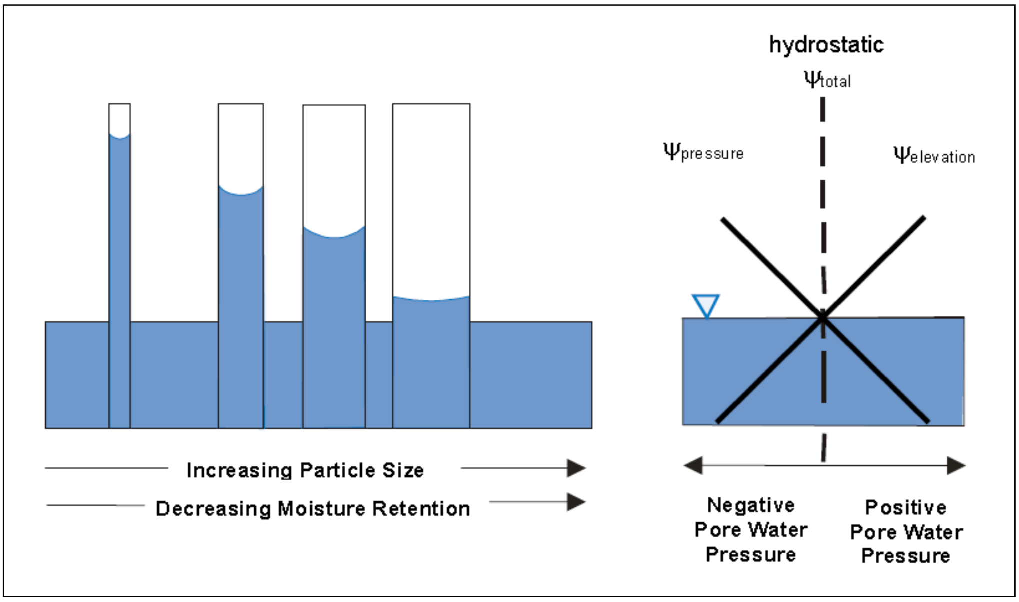


Figure 5 – Sub-atmospheric pressure within a capillary tube (from MEND, 2004)

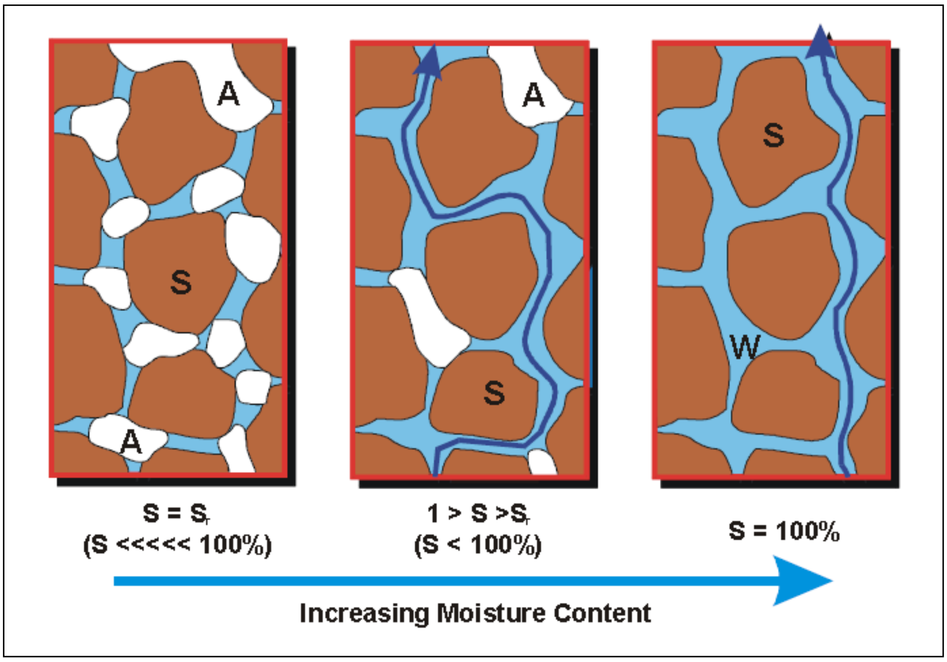


Figure 6 – Schematic representation of a soil mass consisting of solids (S) with voids in between filled with water (W) and air (A) (from MEND, 2004)

3.4 NAF Waste Rock as a Construction Material

It is common for soil cover systems to utilise non-acid forming (NAF) and non-metal leaching waste materials in order to reduce the cost of managing mine waste for closure. However, it is not yet fully appreciated by the mining industry that placement of waste materials that do not meet the textural envelope used in design can have a substantial adverse impact on the performance of the cover (O'Kane and Ayres, 2012). The most common issue is that the waste rock used is too coarse grained and hence the moisture retention within this layer is insufficient (as illustrated in **Figure 5**).

Ideally, a store-and-release layer should comprise a well-graded material ranging from silt/clay size particles up to cobble/boulder size particles. According to O'Kane and Ayres (2012), a good estimate for a store-and-release layer is a well-graded material with at least 40% passing 4.75 mm. If the store-and-release layer is gap graded (sufficient fine and coarse but lacking intermediate sized particles) there is a tendency for the soil to segregate which can lead to macro-pore flow down through the coarser zones, preventing infiltrated water being stored close to the root zone for uptake via evapotranspiration. This may result in failure of the cover system to store the required volume of moisture for any given rainfall event, leading to higher net percolation, infiltration and/or runoff rates.

4 Methodology

4.1 Description of Software

Numerical modelling was undertaken using the finite element package Seep/W 2019 (the 2014 modelling was performed using Vadose/W 2012 which has since been encapsulated within the Seep/W software package). Seep/W enables the analysis of water flow from the environment, across the soil surface, through the unsaturated vadose zone and into the local groundwater regime. Its formulation allows the analysis of problems including infiltration due to rainfall, root transpiration, surface evaporation and runoff.

Key features of the cover modelling in Seep/W include:

- Material properties can be estimated relatively easily using data such as grain-size, saturated hydraulic conductivity and saturated water content, or alternatively they can be imported from the built-in material database if this information is not known.
- Large site-specific climate datasets can be applied to the model over extended time periods using transient analyses. Climate input parameters include temperature (min and max), relative humidity (min and max), wind speed, evaporation and rainfall. These can be specified daily or at any other time interval.

- A 'pan factor' does not need to be applied to the evaporation data. Based on the user input values of potential evaporation (PE), the software computes actual evaporation (AE) as a function of the soil water stress state rather than simply using soil water content, drying time, or empirical user-defined relationships.

Limitations of the cover modelling in Seep/W include:

- Difficulties with numerical convergence can be encountered when the conductivity or volumetric water content functions become relatively steep, as can be found in coarse grained soils. These materials can only sustain a relatively small capillary zone and tend to de-saturate almost completely at small negative pore-water pressures (Geo-Slope, 2014). This was found to be an issue during the modelling in 2014 as the NAF and PAF waste rock materials are generally very coarse grained. Assistance was sought from the Geo-Slope support team, who stated "*Without doubt, the biggest problem with vadose is the numerical simulation of infiltration into very dry soil. The infiltration problem is the most challenging numerical issue that we deal with in all of our software products. In the physical reality, water does infiltrate into very dry soil despite its very low hydraulic conductivity.*" In order to obtain a reasonable solution, very coarse materials were generally assigned gravel properties during the modelling, however it is possible the results using these properties may indicate different runoff and moisture storage values than will be seen in reality.
- Large suction pressures occur within the model (close to the ground surface) due to high evaporation values in the climate boundary conditions. This is linked to the previous point as the conductivity and volumetric water content for coarse grained materials are very low at high suction pressures. Regarding this matter the Geo-Slope support team stated "*…suctions can indeed develop to huge numbers over prolonged drying periods. This is the point at which vadose analysis become very difficult. An attempt to infiltrate water will now likely result in run-off because the conductivity is so low that the upper elements form a 'numerical plug'. The mesh discretization could never capture the physical spatial variation in pore-water pressure.*" As with the previous point, this issue may possibly lead to overstated runoff volumes in the modelling results.

Whilst it is noted that the software does have some limitations in regard to coarse grained materials, the final numerical models for the Project were all found to converge to an acceptable solution within the specified tolerances. In addition, all of the modelling results have been assessed using 'engineering judgement' in order to obtain a realistic solution. Therefore, it is considered that the results presented herein are a reasonable estimation of cover performance. Further testing work on materials breakdown during Project development will allow the modelling to be refined and updated.

4.2 Assumptions

The assumptions made for the Seep/W modelling are summarised in the following sections.

4.2.1 Construction Materials and Cover Profile

Based on a review of the available information regarding the characterisation and availability of materials, the various geotechnical units identified for the Project are described in **Table 1**.

Based on the available materials, a cover profile has been recommended by Soil Management Designs, the specialist consultant undertaking the soils and land capability assessment for the Project and provided by RWC to Advisian. The full depth of this recommended profile is 1.8 m to 3.0 m below ground level (mbgl) and the individual layers are summarised as follows:

- 0.3 m thickness of Topsoil; overlying
- 0.3 m thickness of Subsoil; overlying
- 0.4 m thickness of NAF material, 0.5-30 cm particle diameter; overlying
- 0.4-1.6 m thickness* of NAF material, 30-40 cm particle diameter; overlying
- 0.4 m thickness of compacted Subsoil

** Note: a thickness of 1.6 m was recommended by Soil Management Designs for the NAF material (30-40 cm particle diameter). However, depending on material availability during construction, the thickness of this layer may be reduced if required (minimum 0.4 m thickness is recommended), without having a significant effect on the overall cover performance. As a check, the thickness of this layer was reduced to 1.0 m and 0.4 m during the modelling and the difference in results was negligible due to the material coarseness preventing any significant water flow through this layer.*

The above profile applies to both the TSF and WRE cover systems and has been used as a basis for the cover modelling described in this report. The material parameters assumed for each cover layer are presented in **Table 2** and details on the quantities of materials required during construction are provided in Section 5.2.

Further testing would need to be undertaken during mining operations to confirm the engineering properties of potential cover construction materials.

Table 1 – In situ Soil Units (available construction materials)

Unit	Description
Topsoil	Refers to the upper ~0.2-0.45 m of in situ soil (average around 0.25m) (SOILmgt, 2019).
Subsoil	Refers to all excavatable soils underlying the Topsoil as identified during the site investigation carried out for the Project (SOILmgt, 2019).
NAF Material (Oxide and Fresh NAF / Intermediate NAF Waste Rock)	Refers to all NAF (<0.1% S) and Intermediate NAF (0.1-0.3% S) waste rock recovered during mining operations. The current mining schedule divides the NAF materials into Oxide (10,009 kt) and Fresh (9,808 kt). It is expected that some proportion of the Oxide material will be of sufficiently low strength to be considered "virtually free dig" and potentially suitable for direct use in the TSF and WRE / LGO covers. However, this proportion is currently unknown and for the purposes of this report it is assumed the NAF material will be processed accordingly (e.g. selective stockpiling / screening / crushing / mixing) to achieve the desired grading. Two grading specifications to be considered in the soil cover design (based on advice from the Project specialist soils and land capability consultant) have been provided by R.W. Corkery & Co. (RWC) and are summarised as follows: ▪ NAF material, 0.5-30 cm particle diameter ▪ NAF material, 30-40 cm particle diameter Laboratory testing was undertaken on two shallow Oxide NAF samples. Test certificates are provided in **Appendix B**. The grading results range from clayey gravel to gravel with 15% finer than 75 microns, although available sampling locations were limited to shallow depths and further testing would need to be undertaken during mining operations to confirm material characteristics with depth and the corresponding processing requirements to achieve a useable cover construction material. Based on the available information it is assumed that, on average, the NAF material will have an excavated (loose) density of 1.67 t/m^3 (Oxide) and 1.84 t/m^3 (Fresh).
PAF Waste Rock	Refers to all PAF (>0.3% S) waste materials recovered during mining operations. Based on the fragmentation analysis undertaken for mining feasibility, the waste rock will consist predominantly of cobbles and boulders.

Table 2 – Assumed Material Parameters used in Cover Modelling

Material	Grading Type	Saturated Hydraulic Conductivity (m/s)	Placed Moisture Content (%)	Void Ratio	Porosity
Topsoil	Silt	1.00E-^{07}	12%	0.75	0.43
Subsoil	Silty Clay	1.00E-^{08}	15%	0.69	0.41
NAF material, 0.5cm-30cm	Fine to coarse grained gravel, cobbles and boulders	1.00E-^{03}	8%	0.59	0.37
NAF material, 30cm-40cm	Boulders	1.00E-^{02}	2%	0.47	0.32
PAF Waste Rock	Cobbles and boulders	1.00E-^{02}	2%	0.47	0.32
Tailings	Silt / Clay	2.00E-^{08}	30%	1.04	0.51
GCL	N/A	1.00E-^{11}	-	-	-

4.2.2 Climate Data

Daily rainfall and potential evaporation values were taken from a database compiled for the Project by Jacobs and supplied by RWC to Advisian. Both rainfall and evaporation datasets included 125 years of readings starting from 1889.

When entering the climate data into Seep/W, the daily rainfall can be spread out evenly over a 24 hour period or concentrated within shorter periods to represent particular rainfall events and particular times of day when rainfall occurs. This rainfall distribution has a significant effect on the modelling results as a greater rainfall intensity will generate more runoff with less infiltration, and the evaporation will be affected by whether the rainfall occurs at night or during the day. Due to the data being provided as daily amounts with no details regarding actual rainfall intensity (mm per hour), a nominal rainfall duration of 12 hours per day (on rainy days only), from 12pm to 12am, was assumed. This is considered to be a reasonable assumption at this stage of the Project. However, during rehabilitation trials, the effectiveness of the proposed cover would need to be assessed using site derived pluviography data.

Daily temperature (minimum and maximum), relative humidity (minimum and maximum) and wind speed (average) values were based on average monthly data obtained from the BOM website (Mudgee Airport station no. 62101) for a 20 year period starting from 1994 (first available year of data for this station). During the modelling, all time-steps prior to 1994 (i.e. from 1889-1994) were assigned the same average monthly values as those from beyond 1994. This is considered a reasonable assumption as the modelling results are not as affected by these parameters as much as by rainfall and potential evaporation.

Plots of the climate data used in the modelling are provided in **Appendix C**.

4.2.3 Liners and Drainage

It is assumed the WRE will have an under-drainage system comprising a HDPE liner at the base, with collected water reporting to a leachate pond for collection and re-use within the processing plant during operation. The tailings impoundment area and decant pond within the TSF will be fully underlain by a low permeability layer and it has been assumed the tailings would be close to full saturation upon closure.

4.2.4 Vegetation

The cover profile outlined in Section 4.2.1 was identified by Soil Management Designs, the Project specialist soils consultant as a suitable medium for promoting vegetation growth. Therefore, an allowance was made in the modelling for vegetation coverage across the final TSF and WRE landforms. This has the effect of improving the overall performance of the cover system by enabling transpiration to occur in addition to evaporation.

A nominal set of vegetation parameters were selected for the TSF and WRE vegetation using standard vegetation functions stored within the Seep/W database of example files. A root depth of 40 cm was assumed and the Leaf Area Index (LAI) function was assumed based on an "excellent quality grass". A linear relationship between root density and root depth was assumed (root density = 100% at surface and 0% at base of roots).

The above nominal vegetation parameters are considered reasonable at this stage of the Project. However, prior to placement of the cover, the selection of appropriate plant species for implementation in the cover system must be carefully assessed to ensure the integrity of the cover is maintained after closure.

4.3 Software Processing

A one-dimensional method was adopted in Seep/W for the top surface of the TSF and WRE covers, and a two-dimensional method was used for the WRE side slopes. The basic model geometry is shown in **Figure 7**. The modelling results were generally collected in units of m^3/m^2 which enables the results to be easily converted to total volumes by multiplying the unit runoff, etc., by the total planar surface area of the TSF / WRE.

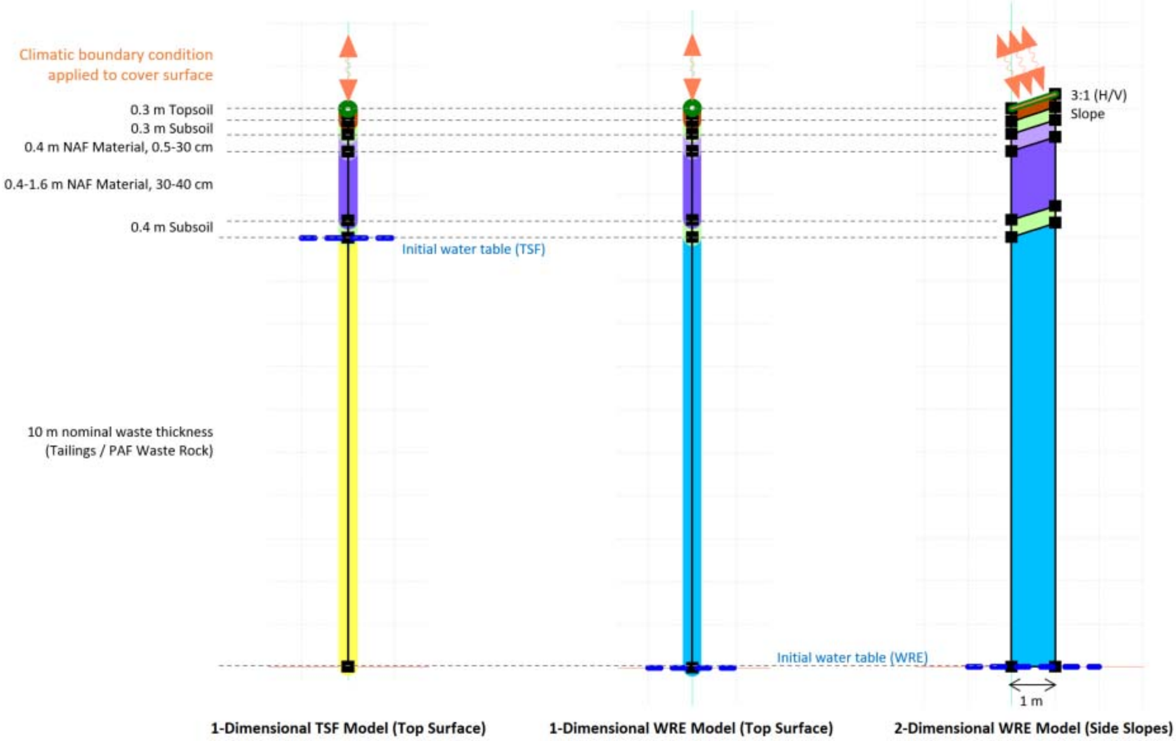


Figure 7 – Seep/W models

The models were run initially for a range of scenarios including varying thicknesses of NAF material, with / without a GCL, and fully saturated / fully dry tailings and PAF waste rock. These initial analyses were aimed at determining whether or not a GCL was likely to be required, how the thickness of the NAF material affected the moisture content of the low permeability materials, and whether the moisture content of the waste materials had an impact on the overall cover performance.

Based on the initial results, the models were refined and re-run using the long-term climate data described in Section 4.2.2, which is considered representative of climatic conditions at the Mine Site over a 125 year period. O'Kane and Ayres (2012) recommend that the climate database for soil cover modelling should comprise at least 50-100 years of daily records from local and regional meteorological stations, which is achieved by the climate data utilised. Each year of the long-term climate database was run continuously for each cover design alternative, thereby taking into account antecedent moisture conditions. This allowed curves to be developed for the various cover alternatives, providing a means of understanding 'risk' or the 'probability of exceeding' a certain event.

It was found during the modelling that the 1-dimensional TSF and WRE top surface models behaved in a similar fashion with negligible differences in the overall results. This may not exactly be the case in reality as the negative pore pressures will differ between the two locations and which will affect storage and flow characteristics, but for the purposes of this assessment it is considered that the results from the 1-dimensional WRE model are also applicable to the TSF cover.

4.4 Modelling Results

The results of the cover modelling are presented in the following sections.

4.4.1 Infiltration Through Base of Cover

The first performance criterion to assess for the models was infiltration of moisture through the base of the cover. This was done by running each model for a typical 'dry', 'average' and 'wet' year based on the long-term climate data. The data subsets extracted from the 125 year dataset and used for these analyses are summarised below:

- Typical 'dry' year: 1919 (annual rainfall 346 mm, potential evaporation 2063 mm)
- Typical 'average' year: 1948 (annual rainfall 678 mm, potential evaporation 1685 mm)
- Typical 'wet' year: 1950 (annual rainfall 1443 mm, potential evaporation 1618 mm)

The TSF top surface model was initially run without a GCL and then with a GCL added beneath the subsoil for comparison. The results are shown in **Figure 8**. These results were obtained during the 2014 modelling but are still considered relevant for the purpose of demonstrating the effect of a GCL.

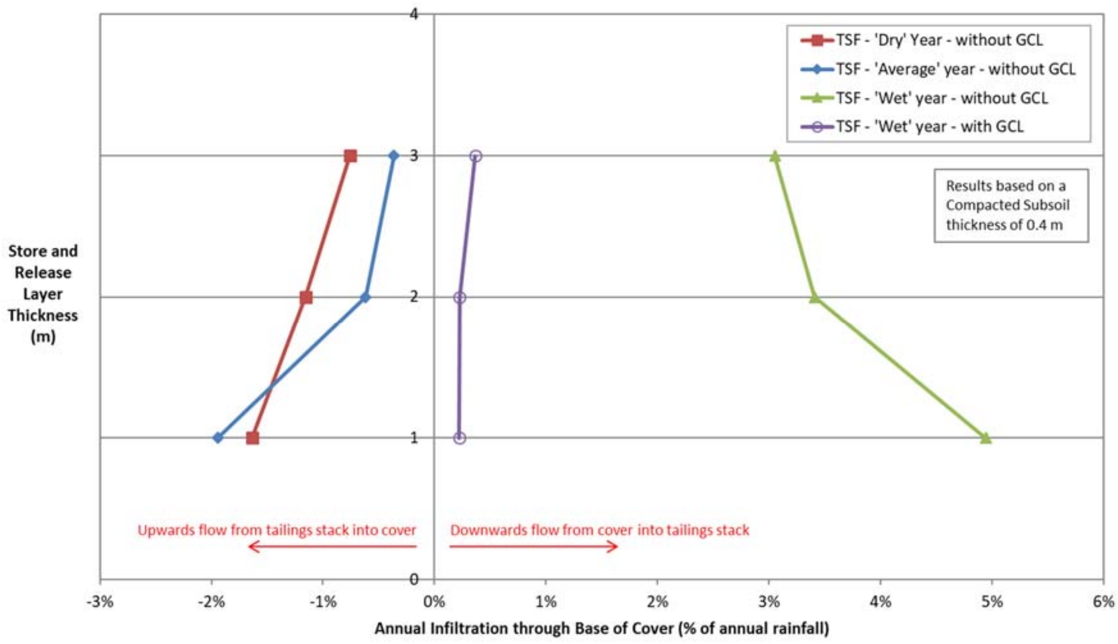


Figure 8 – Infiltration into tailings

Because the average annual evaporation at the Mine Site is greater than the average annual rainfall, the majority of moisture infiltrating the surface of the model during a dry year or an average year will evaporate prior to infiltration occurring. In addition, due to the high water level in the tailings there will be some amount of capillary rise (as described in Section 3.3) which may result in a net upwards movement of water through the cover, as illustrated above in **Figure 8**. For the wet year case, the model showed some net infiltration into the tailings, which was seen to reduce with an increase in the thickness of overlying NAF material due to an increase in the water storage capacity of that layer.

Although the results shown in **Figure 8** can be considered "very low" to "low" (in accordance with O'Kane and Ayres, 2012) rates of net percolation, due to the high degree of saturation within the tailings it would not take long for the TSF to fill up completely under reasonably wet conditions over an extended period. This would lead to issues with potentially contaminated water rising through the base of the cover and mixing with the inert materials above. Therefore, it is recommended that the TSF cover include a GCL at its base, beneath the subsoil layer.

Note that the WRE cover was also analysed for dry, average and wet year conditions and modelling results indicated the WRE would not experience infiltration into the waste, even during a wet year. This appears to be due to the 'capillary break' caused by the fine-grained subsoil layer sandwiched in between the coarser grained NAF and PAF Waste Rock materials, and also because of the high levels of negative pore pressure due to the WRE underdrainage system. Although the model suggests the WRE may perform adequately without a GCL, it is likely that dry/hot periods will lead to shrinkage cracking in the subsoil layer at the base of the cover which will enable infiltration into the PAF waste rock below. Therefore, a GCL is also recommended for the WRE cover at this stage of the Project.

4.4.2 Degree of Saturation

The degree of saturation within a low permeability 'barrier' layer in a cover can significantly affect the overall performance of the cover system. It is ideal to keep the barrier layer as close to saturation as possible in order to prevent the occurrence of shrinkage cracks and also to limit the ingress of oxygen into the underlying waste. This is achieved by providing a sufficient thickness of cover soil above the low permeability layer, which is particularly important for a GCL where desiccation cracks that develop in the thin bentonite layer may not swell shut during rewetting (MEND, 2012).

Figure 9 shows the change in degree of saturation at the base of the compacted subsoil layer over an 'average' rainfall year (1948 dataset) for a 1-dimensional top surface model. These results were obtained during the 2014 modelling but are still considered relevant at this stage of the Project. It is recommended that in order to minimise the loss of saturation at the base of the subsoil and thus within the GCL, the compacted subsoil layer should be not less than 0.4 m thick.

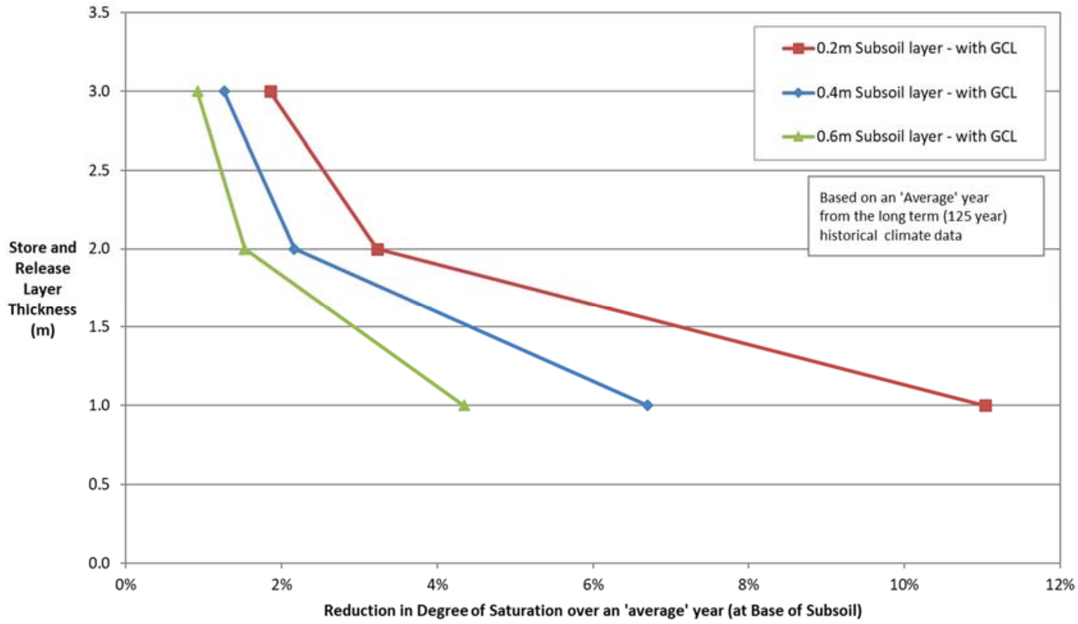


Figure 9 – Degree of saturation

4.4.3 Runoff Volume

For the Project, the use of a GCL is recommended to limit net percolation into the waste rock / tailings and therefore the most relevant modelling result is considered to be surface runoff. A number of probability curves have been developed to enable the reader to assess the probability of exceeding a particular runoff volume in any given year for the proposed cover system.

The finalised models (TSF / WRE top surface and WRE side slopes) were each run for a simulated 125 years in time steps of 2 hours, with the climatic boundary condition varying throughout each day based on the site climate data and the assumed rainfall durations discussed in Section 4.2.2.

From the results of the analysis using the 125 years of data, probability exceedance curves have been generated. These are presented in **Figure 10** and **Figure 11**. An example is given on each figure to assist the reader in their interpretation of the graphs.

Figure 10 and **Figure 11** show the probability of a particular amount of runoff (by volume and also as a percentage of the annual rainfall) occurring in any given year. It is noted that even though these charts indicate there may be up to 33% (top surface) or 47% (side slopes) of the annual rainfall converted into runoff, many of the low intensity rainfall events may not actually generate runoff and a large part of the total annual runoff is likely to occur due to a relatively small number of long duration / high intensity events.

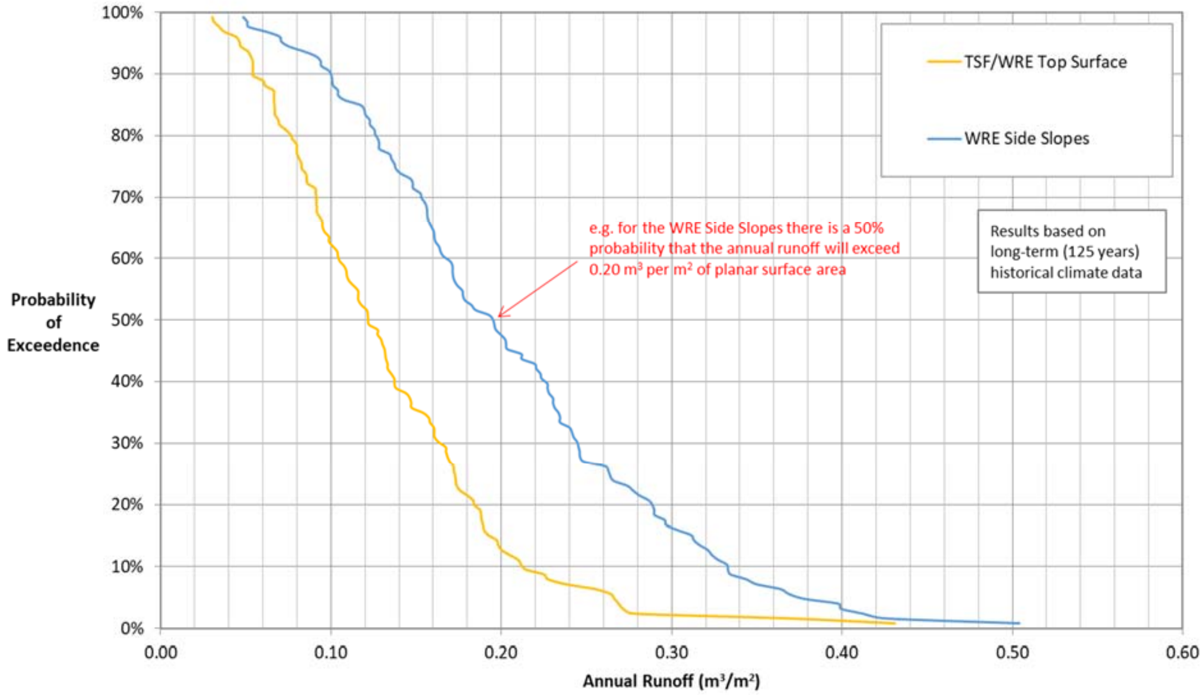


Figure 10 – Annual runoff volume

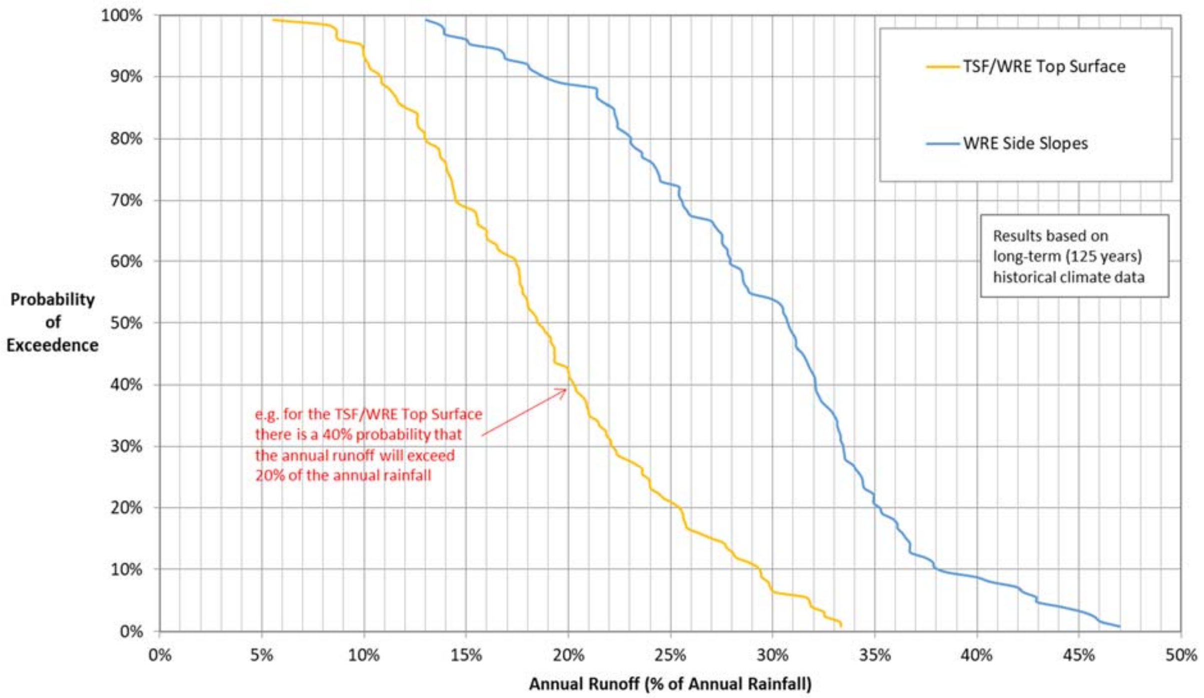


Figure 11 – Annual runoff as percentage of annual rainfall

4.4.4 Probability of Runoff Occurring

According to the modelling, there is no particular type of rainfall event that will act as a threshold causing runoff to commence as there are multiple factors influencing runoff generation, including climate conditions (potential evapotranspiration in particular), moisture content of the soil, porosity of the soil and rainfall duration and intensity. For example, a relatively light rainfall event in the middle of winter when the ground is already close to saturation may generate runoff due to the lack of available storage in the soil, whereas a heavier rainfall in summer when the potential evaporation is high may not cause any runoff at all.

Notwithstanding the above, it must be noted that in reality when the rainfall intensity exceeds the infiltration rate of the soil, runoff will occur irrespective of whether the ground is saturated or not.

5 Conclusions and Recommendations

Based on the information presented in this report, the following conclusions and recommendations are made.

5.1 Recommended Cover System

The cover system recommended for the Project for the TSF and WRE (including side slopes) is summarised below and details are provided on Drawing 201012-00683-CI-DSK-0001 included in Appendix A.

- Minimum 0.3 m thickness of topsoil; underlain by
- Minimum 0.3 m thickness of NAF material (0.5-30 cm particle diameter); underlain by
- 0.4-1.6 m thickness of NAF material (30-40 cm particle diameter); underlain by
- Minimum 0.4 m thickness of compacted subsoil; underlain by
- GCL

** Note: a thickness of 1.6 m was recommended by Soil Management Designs for the NAF material (30-40 cm particle diameter). However, depending on material availability during construction, the thickness of this layer may be reduced if required (minimum 0.4 m thickness is recommended), without having a significant effect on the overall cover performance. As a check, the thickness of this layer was reduced to 1.0 m and 0.4 m during the modelling and the difference in results was negligible due to the material coarseness preventing any significant water flow through this layer.*

Based on the exceedance probability curves presented in Section 4.4, a suitable runoff volume should be selected for each of the covers for input into drainage design.

The TSF cover system shown in **Appendix A** follows the expected final tailings beach surface as far as practicable, with adjustments made to shed the water towards the closure spillway located on the north abutment.

The final TSF landform surface will need to be adjusted to suit the final tailings beach surface, complying with the minimum thicknesses of cover materials presented above. The final cover thickness will also need to be adjusted across the TSF to allow for future consolidation of the underlying tailings.

5.2 Cover quantities

Table 3 presents the calculated quantities of construction materials required for the recommended TSF and WRE cover systems, based on the modelled geometries of both structures, including necessary adjustments in the TSF surface towards the spillway. Quantities were also based on the following assumptions:

- Subsoil (includes Clay/Silts and Sand/Grits) thickness is variable across the Mine Site but sufficient quantity is assumed to be available for use as the minimum 0.4 m protective layer (cushion layer) above the CGL. Depending on actual availability of materials during mining, the cushion layer may also be constructed using oxide NAF material provided it is characterized as clay.
- Most of the Oxide NAF material for the store-and-release layer at the TSF will be reclaimed from the Southern barrier.
- The thickness of the NAF material (30-40 cm) has been adjusted where required to enable drainage of the cover surface towards the TSF spillway.

Table 3 – Material quantities

Material	TSF	WRE (including side slopes)
0.3 m Topsoil	381,177 m^3	199,323 m^3
0.3 m Subsoil	381,177 m^3	199,323 m^3
0.4 m NAF material (0.5-30 cm)	579,086 m^3	254,118 m^3
0.4 m to 1.6 m Oxide material (30-40 cm)	2,316,344 m^3	254,118 m^3 (0.4 m) 508, 236 m^3 (0.8 m) 762,354 m^3 (1.2 m) 1,016,472 m^3 (1.6m)
0.4 m Compacted Subsoil	427,015 m^3	259,580 m^3
GCL	1,125,305 m^2	532,170 m^2

5.3 Further Work

The following additional work is recommended to be undertaken during mining operations, to assist in finalising the design of the cover system:

- Particle size distribution (PSD) testing of all materials, particularly the NAF material, to obtain an understanding of variation with depth and material processing requirements.
- Assessment of how the NAF materials will break down during handling (excavation and stockpiling), weathering and compaction.
- Testing of soil hydraulic properties to develop volumetric water content and hydraulic conductivity functions for all cover materials.
- Analysis of pluviograph data (rainfall provided in 1 minute intervals) to optimise the climatic functions applied to the cover model.
- Assessment of vegetation species suitable for the cover.
- Preparation of a trial area with Lysimeters to monitor moisture in the soil and calibrate the cover models.
- Assessment of the expected consolidation of the deposited tailings in order to compensate the thickness of the store-and-release layer to maintain the slope of the cover surface towards the closure spillway.

5.4 Construction Considerations

The following recommendations should be adhered to during construction of the cover systems:

- A suitable bedding material (oxide PAF) must be laid prior to placing the GCL over the WRE to prevent puncturing of the GCL by underlying rock. Given the fine nature of the tailings material, a protective layer is not considered necessary over the tailings beach.
- The topsoil, upper subsoil and NAF cover layers should be placed in a loose state to maximise water storage and facilitate vegetation root growth.

5.5 Operational Monitoring

The main objectives of monitoring the performance of cover systems are to refine the site water balance, obtain field performance data to calibrate numerical models, assess the performance of the cover system and develop an understanding of the key site characteristics and processes that control soil cover performance. Operational monitoring of the cover system will also provide an indicator of when remedial measures may be required to repair defects such as cracking, erosion, disturbance by tree roots, and burrowing by animals or insects. (Williams, 2013)

Monitoring of the cover system should include:

- Visual assessments particularly during the period immediately following installation;
- Flow monitoring in water management infrastructure; and
- Monitoring moisture levels in the soil using lysimeters.

6 References

Advisian (2019): Preliminary Design of PAF Waste Rock Emplacement, Low Grade Ore and Oxide Ore Stockpiles and the Southern Barrier, Bowdens Silver Project, issued in March 2019.

ATC Williams (2020): Tailings Storage Facility Preliminary Design, May 2020, Part 16A of the Specialist Consultant Studies Compendium. Prepared for Bowdens Silver Pty Limited.

GARD (Global Acid Rock Drainage Guide) (2012): http://www.gardguide.com

Geo-Slope (2014): Vadose Zone Modelling with Vadose/W, An Engineering Methodology; May 2014 Edition; http://www.geo-slope.com

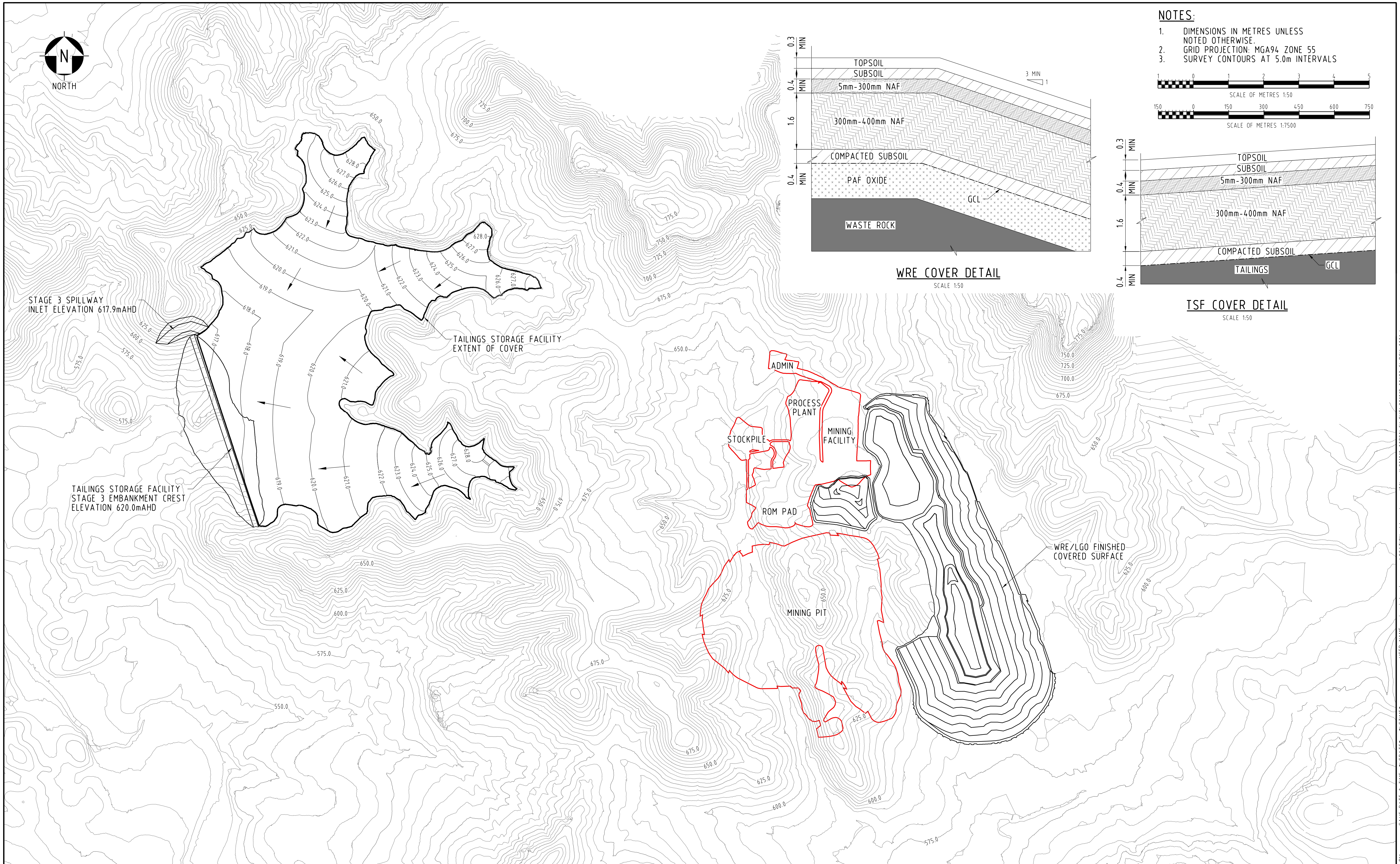
MEND (Mine Environment Neutral Drainage Program) (2004): Design, construction and performance monitoring of cover systems for waste rock and tailings; Report 2.21.4, Volume 1

MEND (Mine Environment Neutral Drainage Program) (2012): Cold regions cover system design technical guidance document; Report 1.61.5c

O'Kane, M.A. and Ayres, B. (2012): Cover systems that utilise the moisture store-and-release concept – do they work and how can we improve their design and performance?; Proceedings of the Seventh International Conference on Mine Closure, 25-27 September 2012, Brisbane, Australia

Williams (2013): Improving performance of soil covers over waste rock dump tops in dry climates; Proceedings of the Eighth International Conference on Mine Closure, 18-20 September 2013, Cornwall, England

Appendix A TSF and WRE Cover Systems



NOTES:

1. DIMENSIONS IN METRES UNLESS NOTED OTHERWISE.
2. GRID PROJECTION: MGA94 ZONE 55
3. SURVEY CONTOURS AT 5.0m INTERVALS

SCALE OF METRES 1:50

SCALE OF METRES 1:7500

REV	DATE	REVISION DESCRIPTION	DRAWN	DRAFT CHK	DESIGNED	ENG CHK	APPROVED	CLIENT	REF DRAWING No	REFERENCE DRAWING TITLE
0	24-JUN-19	ISSUED FOR USE	SL							

A1 SHEET SCALE AS SHOWN

OneWay to zero harm

ADVISIAN PROJECT No. 201012-00683

ENGINEERING AND PERMIT STAMPS (As Required)

CLIENT

BOWDENS SILVER

Advisian
WorleyParsons Group

BOWDENS SILVER PTY LTD
BOWDENS SILVER PROJECT
TSF AND WRE
CLOSURE COVER DESIGN

DRG No 201012-00683-CI-DSK-0001 REV 0

ADVISIAN_A1

LOCATION: \\aupdcwpcad01\cad\201010-00790\CI\SKE\201012-00683-CI-DSK-0001.dgn
USER NAME: simonie.laval
SAVE DATE & TIME: $LSDATE$ $LSTIME$
PLOT DATE & TIME: 12/06/2019 2:32:32 PM

Appendix B Laboratory Test Certificates

Golder Associates

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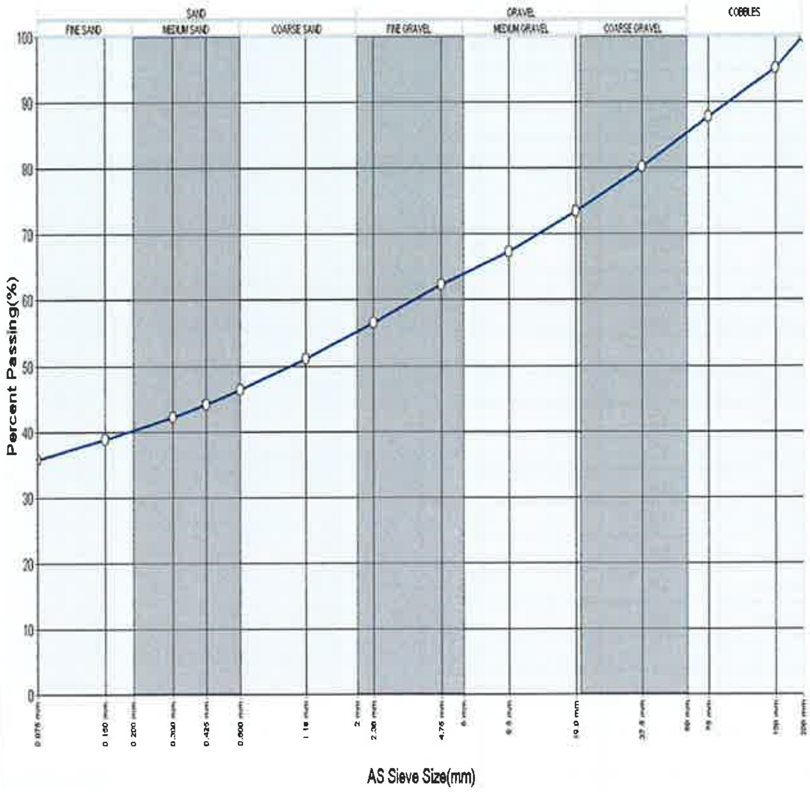
Particle Size Distribution Report

Client :	Kingsgate Consolidated Limited	Report Number:	1413221 - 1
Address :	68 Maloneys Road, Lue, NSW	Report Date :	16/09/2014
Project Name :	Kingsgate Bowdens Silver Project	Order Number :	
Project Number :	1413221	Test Method :	AS1289.3.6.1
Location:	Bowdens PSD		Page 1 of 2

Sample Number :	14301705	SAMPLE LOCATION	
Sampling Method :	-	BowPSD01	
Sampled By :	Client's Rep.		
Date Sampled / Received:	8/09/2014		
Date Tested :	11/09/2014		
Material Type :	-	Test Number :	
Material Source :	-	Lot Number :	
Remarks :		Specification Number :	

AS Sieve Size(mm)	Percent Passing	Specification Limits
200	**100**	
150	**95**	
100		
75	**88**	
63		
53		
37.5	**80**	
19.0	**73**	
13.2		
9.5	**67**	
6.7		
4.75	**62**	
2.36	**56**	
1.18	**51**	
0.600	**46**	
0.425	**44**	
0.150	**39**	
0.150	**39**	
0.075	**36**	



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Nick Farrer - Senior Technical Officer
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FORM NUMBER : R77-RL-16

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Particle Size Distribution Report

Client :	Kingsgate Consolidated Limited	Report Number:	1413221 - 1
Address :	68 Maloneys Road, Lue, NSW	Report Date :	16/09/2014
Project Name :	Kingsgate Bowdens Silver Project	Order Number :	
Project Number :	1413221	Test Method :	AS1289.3.6.1
Location:	Bowdens PSD		Page 2 of 2

Sample Number :	14301706	SAMPLE LOCATION
Sampling Method :	-	BowPSD02
Sampled By :	Client's Rep.	
Date Sampled / Received:	8/09/2014	
Date Tested :	11/09/2014	
Material Type :	-	Test Number :
Material Source :	-	Lot Number :
Remarks :		Specification Number :

AS Sieve Size(mm)	Percent Passing	Specification Limits
200	100	
150	97	
100		
75	79	
63		
53		
37.5	64	
19.0	51	
13.2		
9.5	43	
6.7		
4.75	37	
2.36	32	
1.18	27	
0.600	24	
0.425	22	
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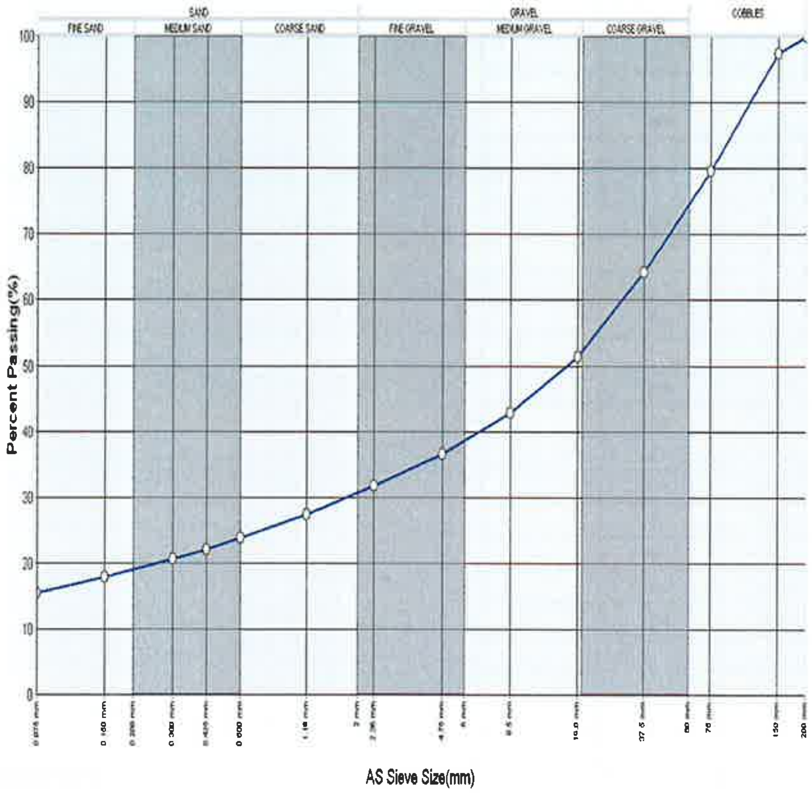
0.150	18	
0.075	15	



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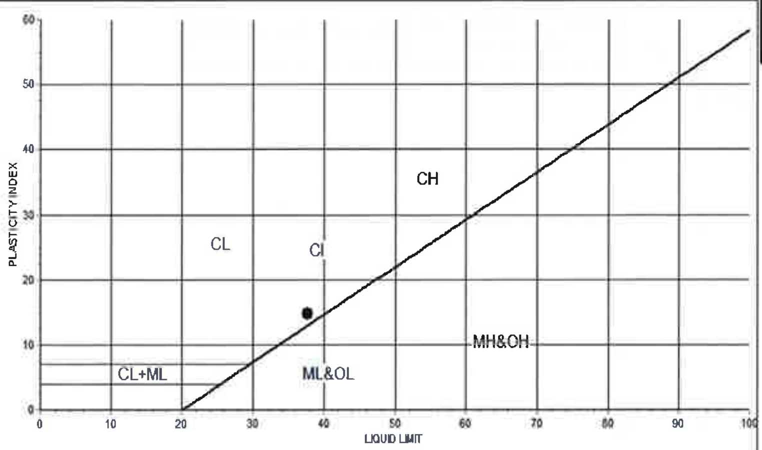
Atterberg Limits Report

Client:	**Kingsgate Consolidated Limited**	Report Number:	**1413221 - 4**
Client Address:	**68 Maloneys Road Lue NSW**		
Job Number:	**1413221**	Report Date:	**16/09/2014**
Project:	**Kingsgate Bowdens Silver Project**	Order Number:	-
Location	**Bowdens PSD ,**		Page 1 of 2
Lab No:	**14301705**	Sample Location	
Date Sampled / Received:	**8/09/2014**	BowPSD01	
Date Tested:	**15/09/2014**		
Sampled By:	**Client's Rep.**		
Sample Method:	-		
Material Source:	-	Spec Description:	-
For Use As:	-	Lot Number:	-
Remarks:	-	Spec Number:	-

Plasticity Tests		Test Method	Specification Minimum	Result	Specification Maximum
Sample History:	Oven Dried low temp.				
Moisture Content (%):°C	-	-	-		-
Liquid Limit (%)		**AS1289.3.1.1**		**38**	
Plastic Limit (%)		**AS1289.3.2.1**		**23**	
Plasticity Index (%)		**AS1289.3.3.1**		**15**	
Linear Shrinkage (%)		**AS1289.3.4.1**		**6.5**	
			Linear Shrinkage State after drying	No crumbling or curling	



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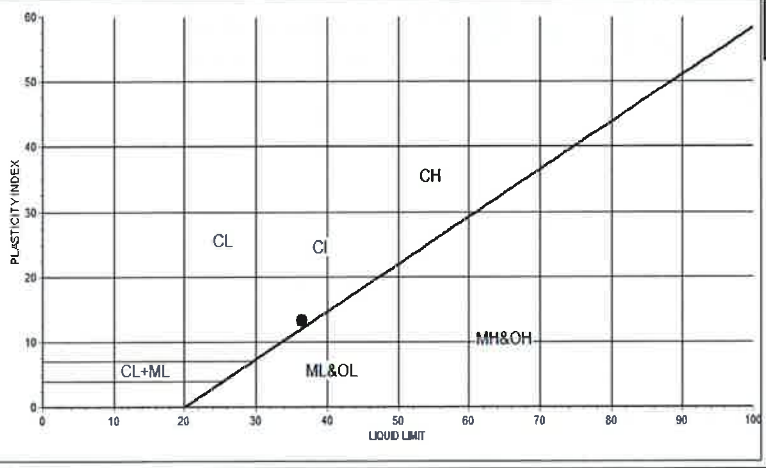
Atterberg Limits Report

Client:	**Kingsgate Consolidated Limited**	Report Number:	**1413221 - 4**
Client Address:	**68 Maloneys Road Lue NSW**		
Job Number:	**1413221**	Report Date:	**16/09/2014**
Project:	**Kingsgate Bowdens Silver Project**	Order Number:	-
Location	**Bowdens PSD ,**		Page 2 of 2
Lab No:	**14301706**	Sample Location	
Date Sampled / Received:	**8/09/2014**	BowPSD02	
Date Tested:	**15/09/2014**		
Sampled By:	**Client's Rep.**		
Sample Method:	-		
Material Source:	-	Spec Description:	-
For Use As:	-	Lot Number:	-
Remarks:	-	Spec Number:	-

Plasticity Tests		Test Method	Specification Minimum	Result	Specification Maximum
Sample History:	Oven Dried low temp.				
Moisture Content (%):°C	-	-	-		-
Liquid Limit (%)		**AS1289.3.1.1**		**37**	
Plastic Limit (%)		**AS1289.3.2.1**		**23**	
Plasticity Index (%)		**AS1289.3.3.1**		**14**	
Linear Shrinkage (%)		**AS1289.3.4.1**		**7.0**	
			Linear Shrinkage State after drying	No crumbling or curling	



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Apparent Particle Density Report

Client :	**Kingsgate Consolidated Limited**	Report Number:	**1413221 - 2**
Client Address:	**68 Maloneys Road Lue NSW**		
Job Number :	**1413221**	Report Date:	**16/09/2014**
Project :	**Kingsgate Bowdens Silver Project**	Order Number:	
Location :	**Bowdens PSD**	Test Method:	**AS1289.3.5.1**

Lab No :	14301705	14301706		
ID No :	-	-		
Lot No :	-	-		
Item No :	-	-		
Date Sampled :	8/09/2014	8/09/2014		
Date Tested :	16/09/2014	16/09/2014		
Material Source :	-	-		
For Use As :	-	-		
Sample Location :	BowPSD01	BowPSD02		
Apparent Particle Density(t/m^3)	**2.47**	**2.56**		

Remarks :

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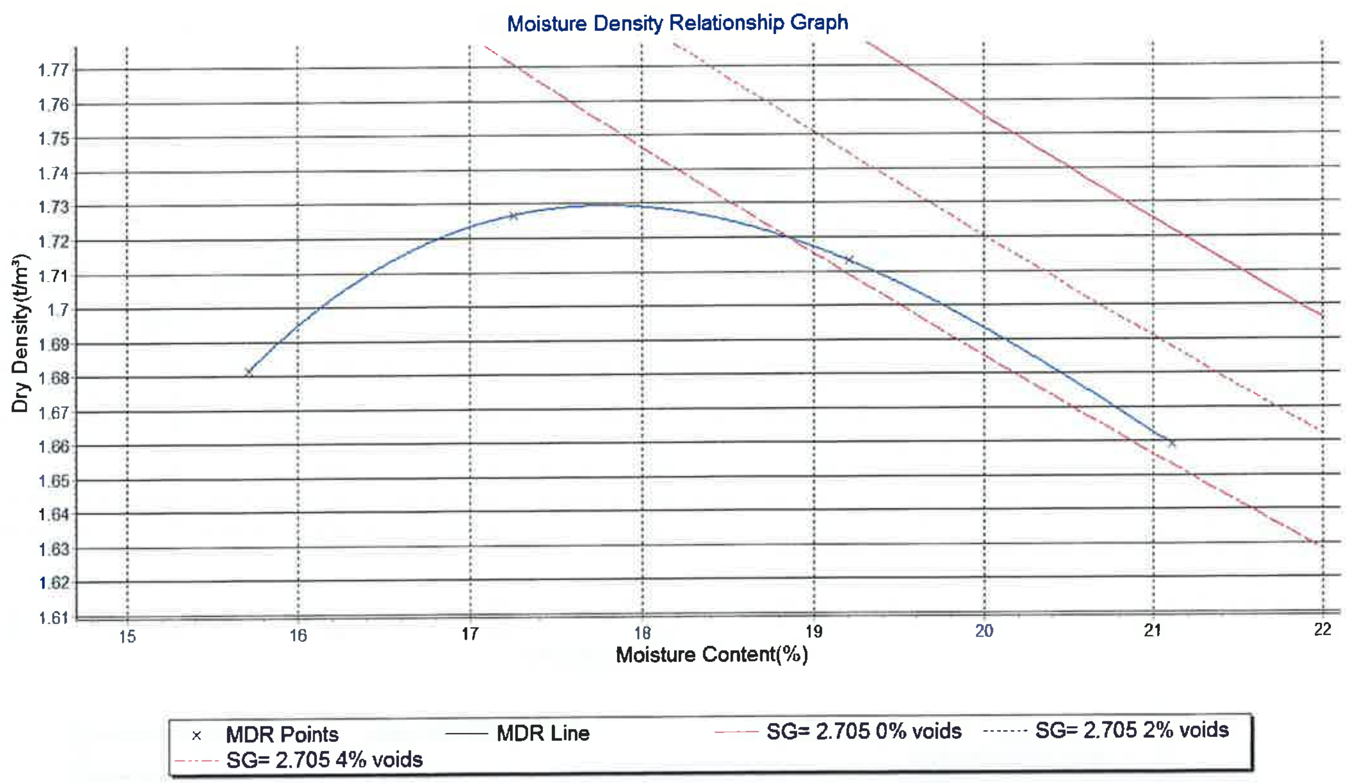
Dry Density Moisture Relationship Report

Client:	Kingsgate Consolidated Limited	Report Number:	1413221 - 3
Client Address:	68 Maloneys Road Lue NSW		
Job Number:	1413221	Report Date:	16/09/2014
Project:	Kingsgate Bowdens Silver Project	Order Number:	
Location	Bowdens PSD ,	Test Method :	AS1289.5.1.1
Lab No:	14301705	Sample Location	BowPSD01
Date Sampled /Received:	8/09/2014		
Date Tested:	11/09/2014		
Sampled By:	Client's Rep.		
Sample Method:	-		
Material Source:	-		
For Use As:	-	Lot Number:	-
Remarks:	-	Item Number :	-

Maximum Size (mm) :	19.0	Moisture Content Test Method :	AS1289.2.1.1
Oversize (%) :	-	As Received Moisture Content (%) :	
MDD (t/m³) :	**1.730**	Oversize Test Method :	-
OMC(%) :	**17.8**	Oversize Density (t/m³) :	



Accredited for compliance with ISO/IEC 17025.
THIS DOCUMENT SHALL ONLY BE REPRODUCED IN FULL

Approved Signatory

Geoff Hooper - Senior Technical Officer

NATA Accred No:1961

Form Number : R70-RL-18

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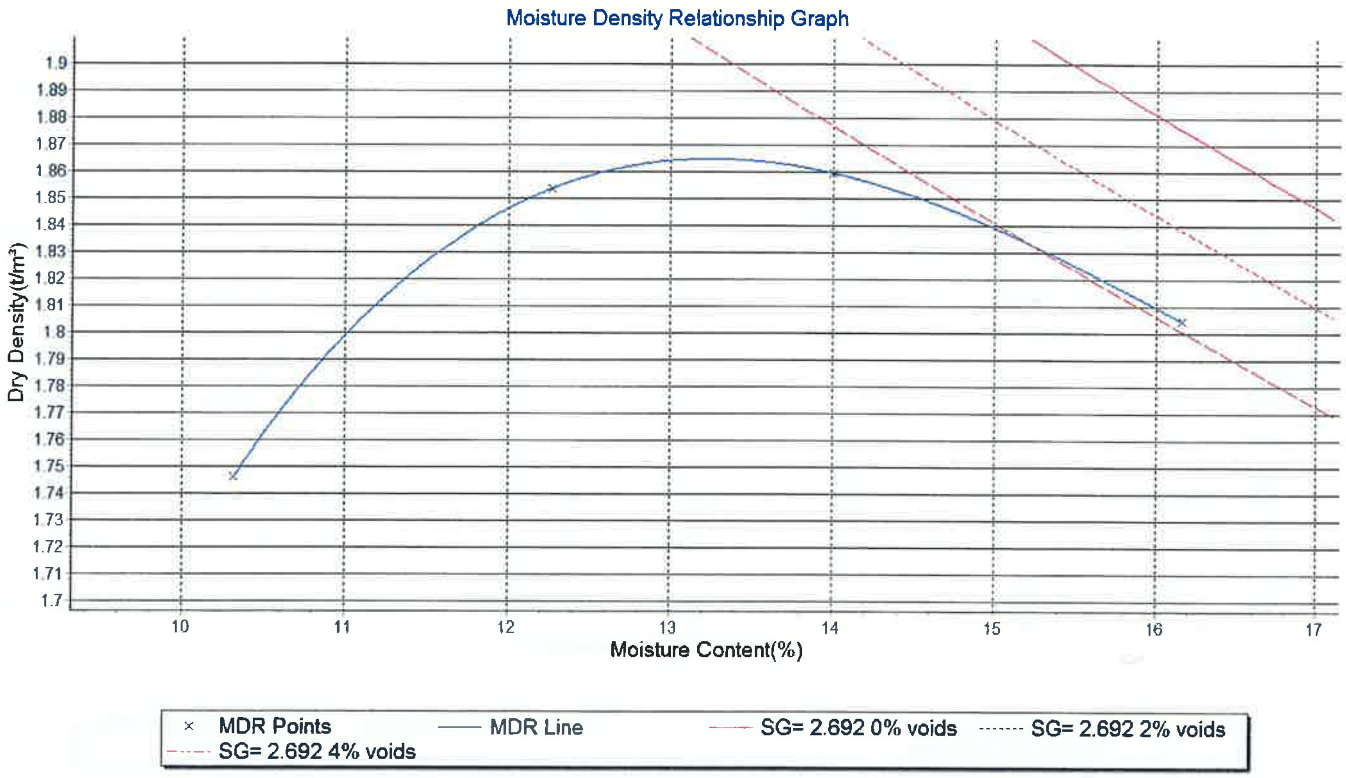
Dry Density Moisture Relationship Report

Client:	**Kingsgate Consolidated Limited**	Report Number:	**1413221 - 3**
Client Address:	**68 Maloneys Road Lue NSW**		
Job Number:	**1413221**	Report Date:	**16/09/2014**
Project:	**Kingsgate Bowdens Silver Project**	Order Number:	
Location	**Bowdens PSD ,**	Test Method :	**AS1289.5.1.1**
Lab No:	**14301706**	Sample Location	
Date Sampled /Received:	**8/09/2014**	BowPSD02	
Date Tested:	**11/09/2014**		
Sampled By:	**Client's Rep.**		
Sample Method:	-		
Material Source:	-		
For Use As:	-	Lot Number:	-
Remarks:	-	Item Number :	-

Maximum Size (mm) :	**19.0**	Moisture Content Test Method :	**AS1289.2.1.1**
Oversize (%) :	-	As Received Moisture Content (%) :	
MDD (t/m³) :	**1.865**	Oversize Test Method :	-
OMC(%) :	**13.3**	Oversize Density (t/m³) :	



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Approved Signatory

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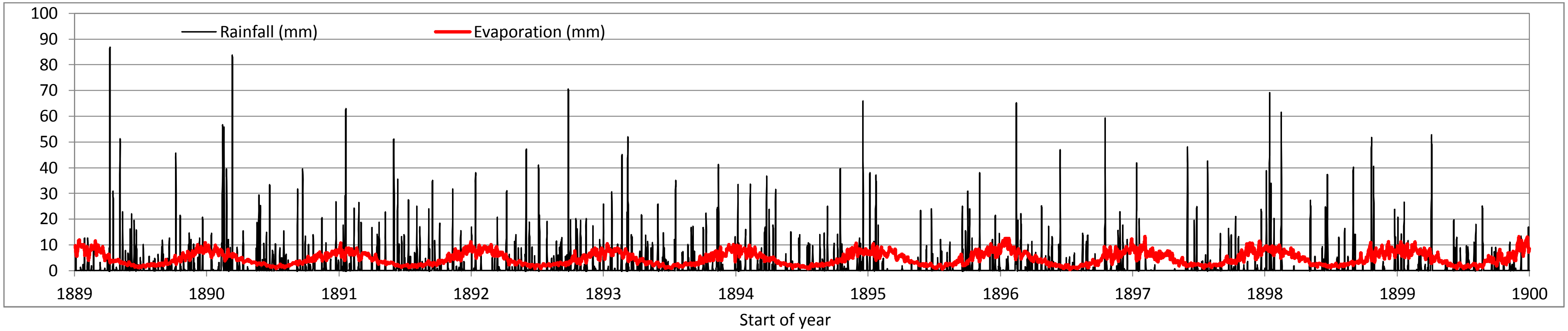
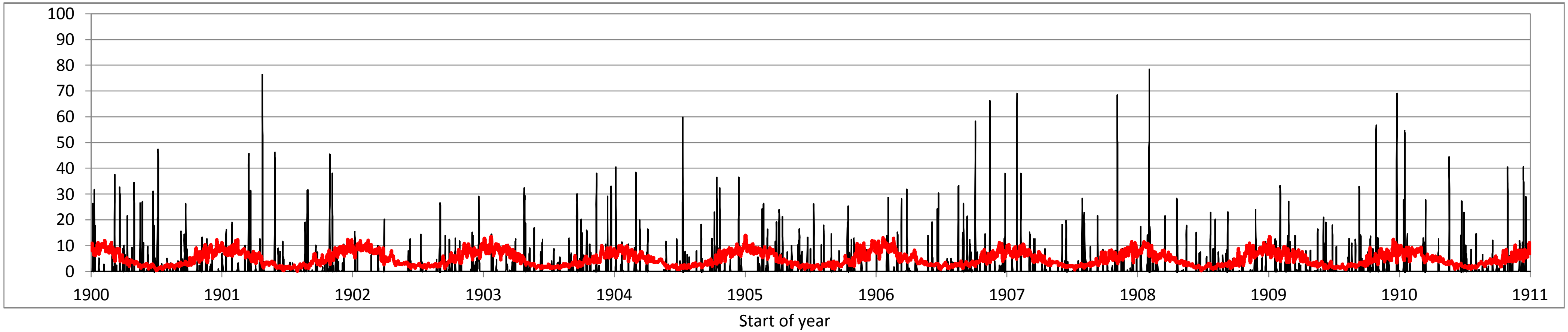
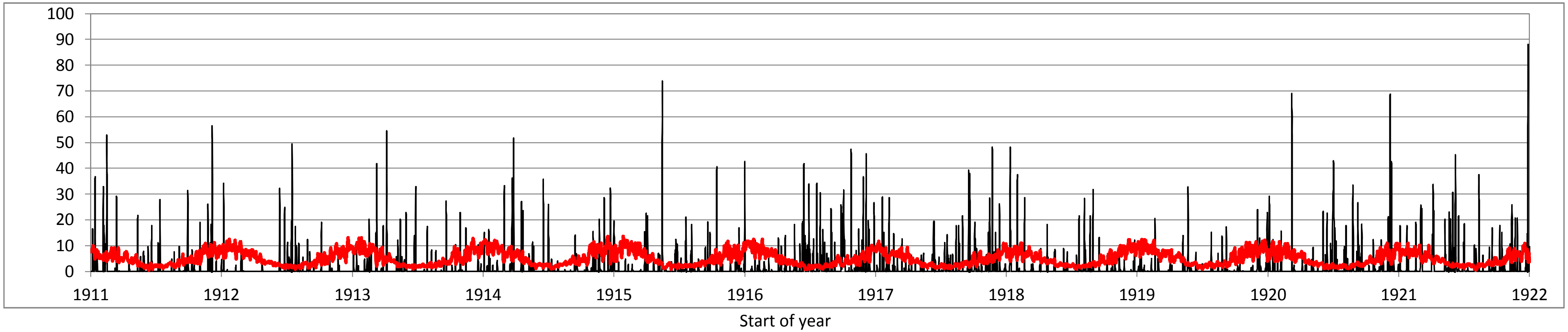
Appendix C Climate Data Used in Analysis

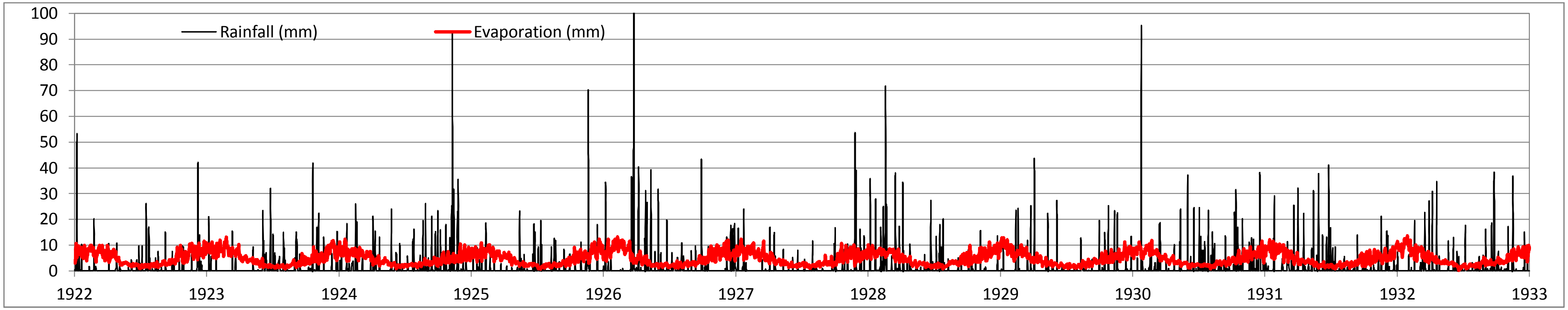
Historical Rainfall and Evaporation data used in Vadose/W analyses 1889 - 1922

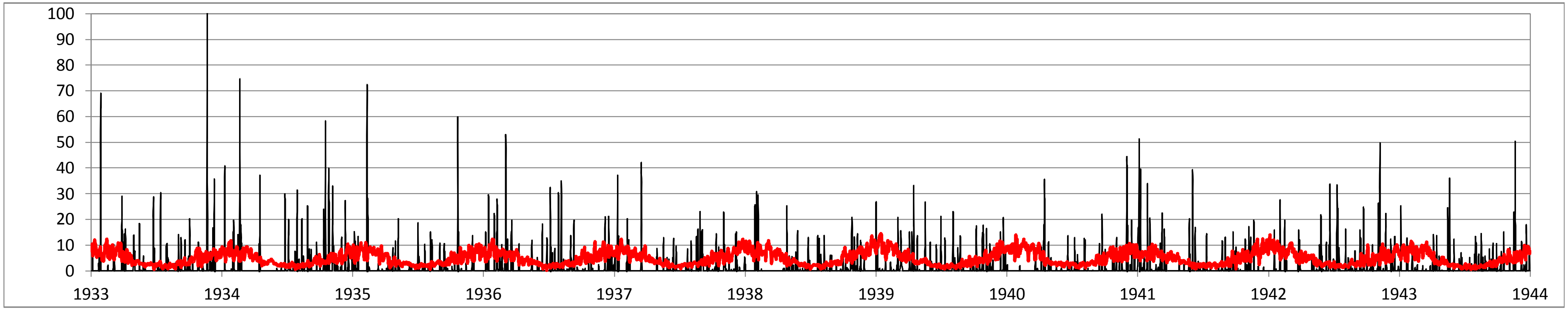


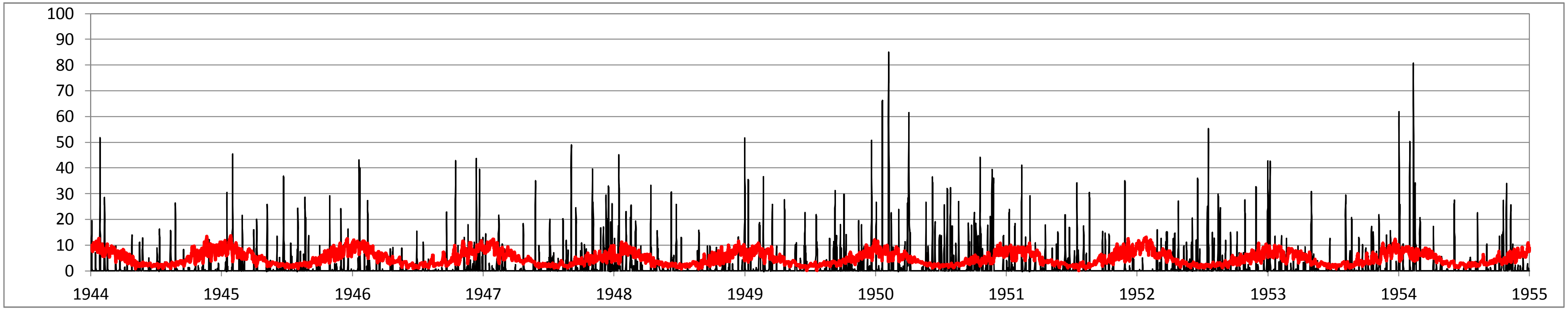




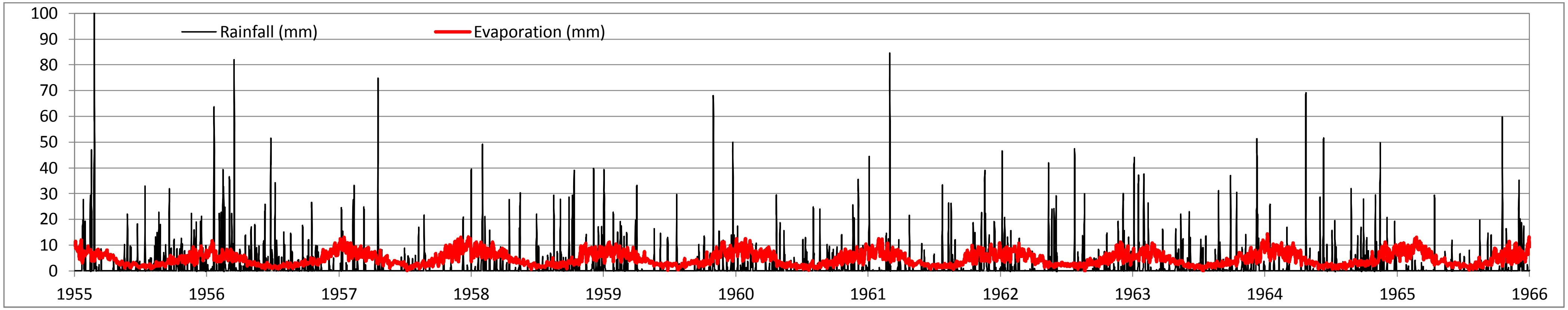
Historical Rainfall and Evaporation data used in Vadose/W analyses 1922 - 1955

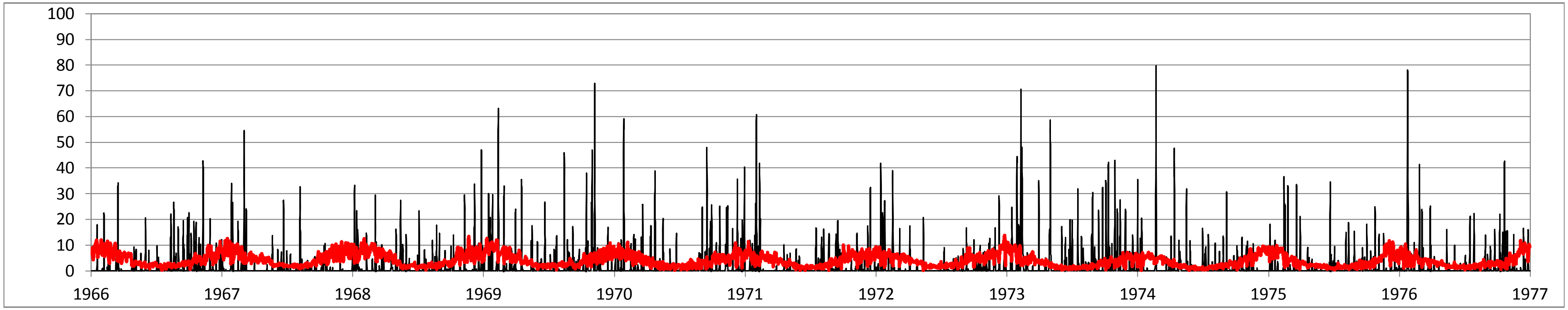


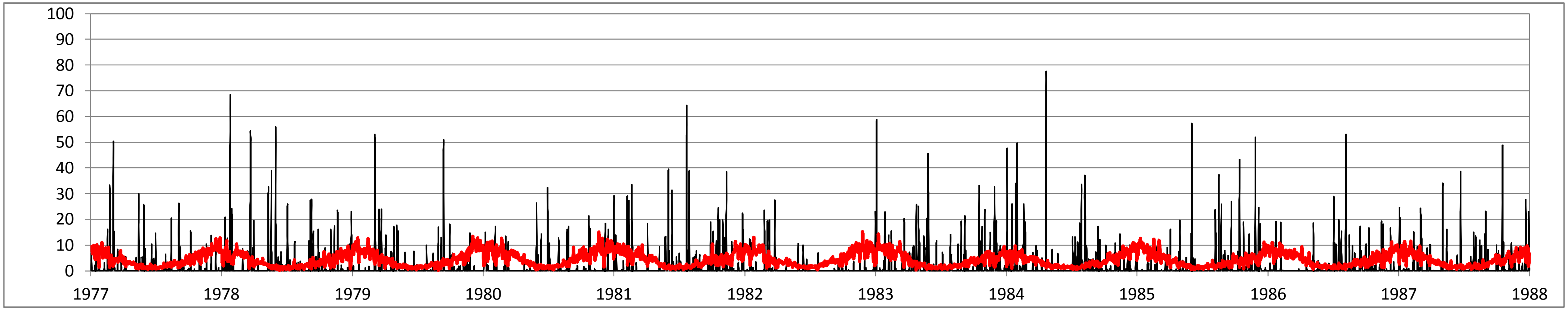




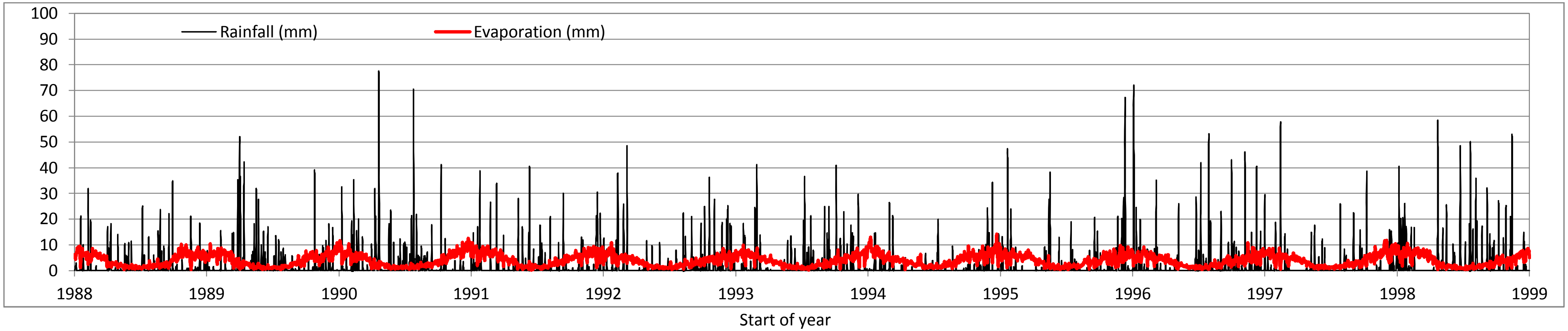
Historical Rainfall and Evaporation data used in Vadose/W analyses 1955 - 1988

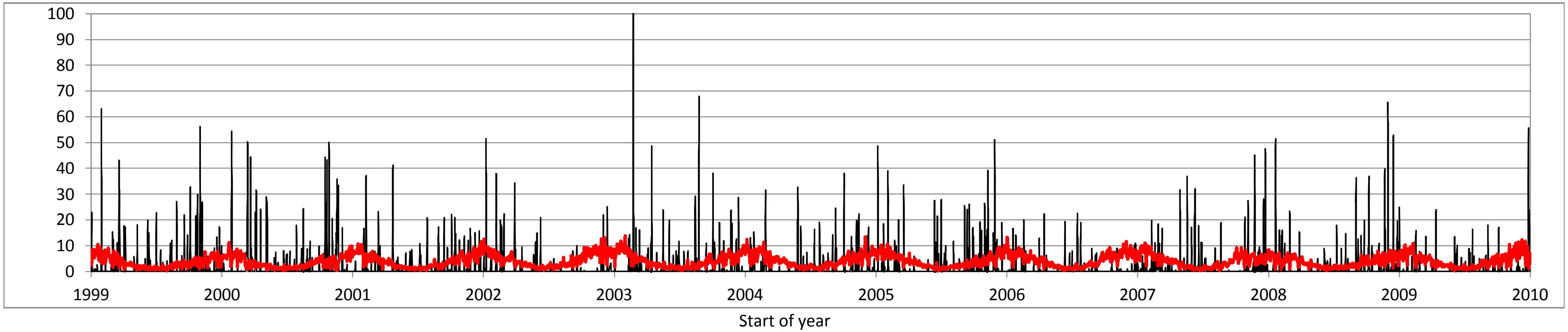


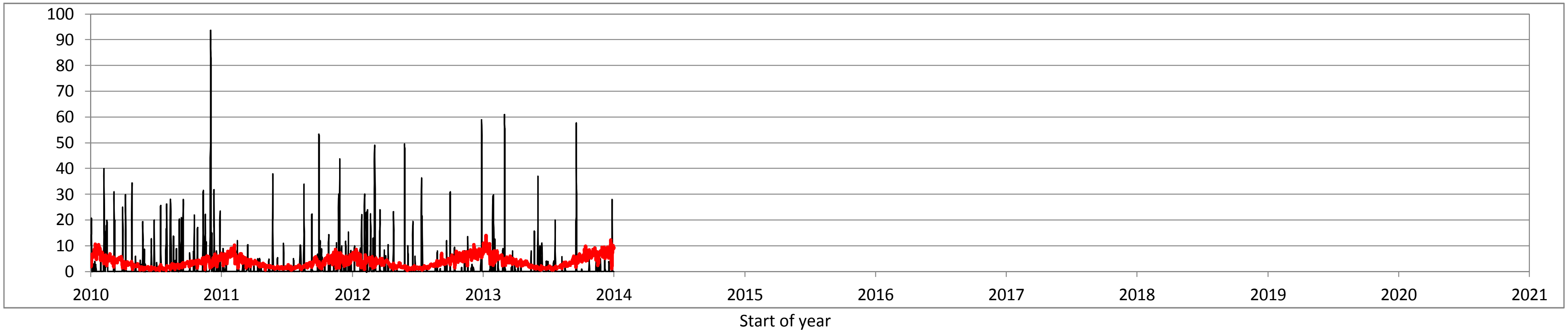


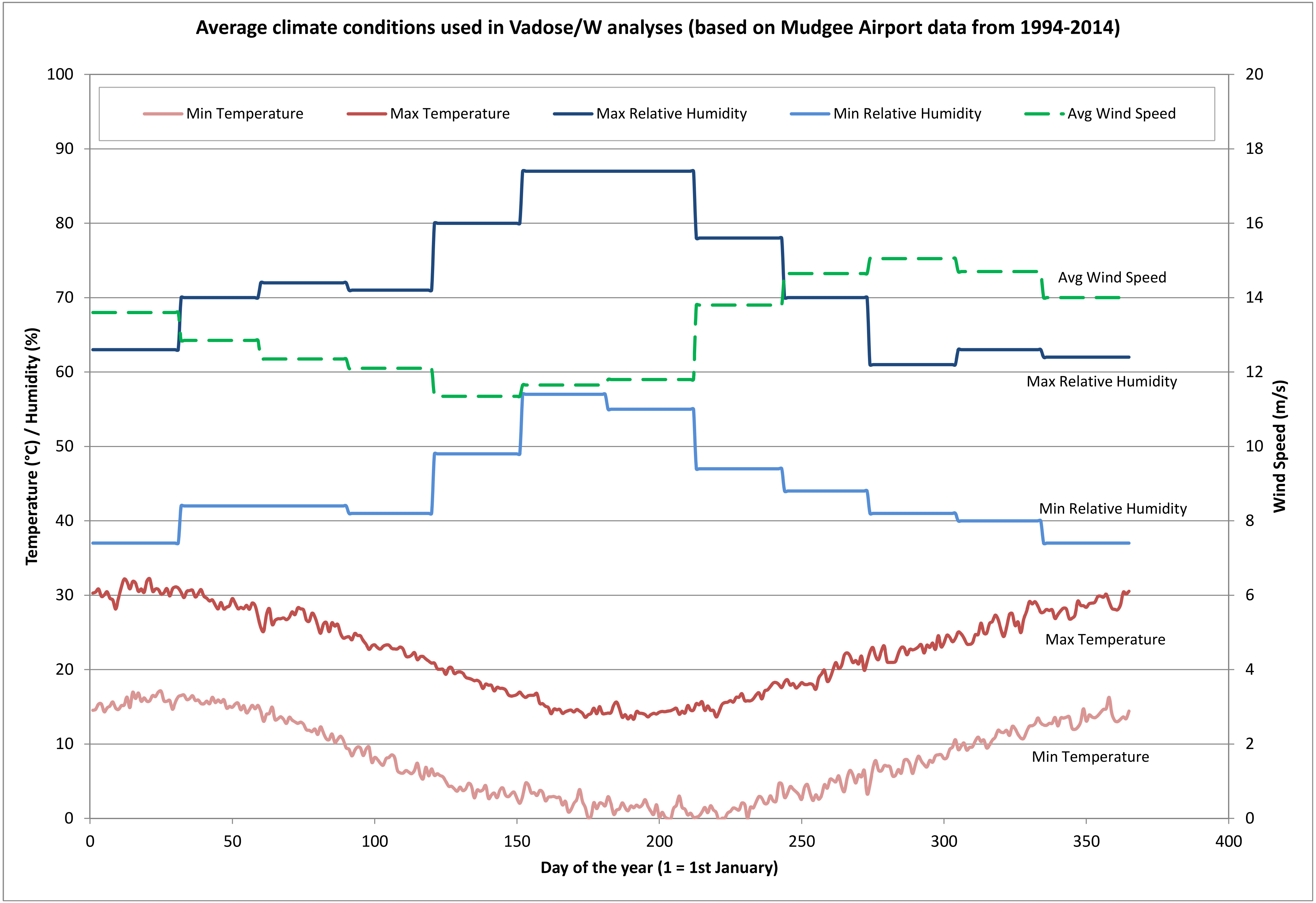


Historical Rainfall and Evaporation data used in Vadose/W analyses 1988 - 2014









Average climate conditions used in Vadose/W analyses (based on Mudgee Airport data from 1994-2014)
Min Temperature
Max Temperature
Max Relative Humidity
Min Relative Humidity
Avg Wind Speed
Avg Wind Speed
Max Relative Humidity
Min Relative Humidity
Max Temperature
Min Temperature
Temperature (°C) / Humidity (%)
Wind Speed (m/s)
Day of the year (1 = 1st January)
0
10
20
30
40
50
60
70
80
90
100
0
2
4
6
8
10
12
14
16
18
20
0
50
100
150
200
250
300
350
400